

GUIDELINES FOR MAINTENANCE, REPAIR AND REHABILITATION OF CEMENT CONCRETE PAVEMENTS

(First Revision)

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GUIDELINES FOR MAINTENANCE, REPAIR AND REHABILITATION OF CEMENT CONCRETE PAVEMENTS

1 INTRODUCTION

1.1 Concrete Pavements also known as Rigid Pavements have a relatively long service life, provided these are properly designed, constructed and maintained. With mega projects like National Highway Development Project (NHDP), Special Accelerated Road Development Project (SARDP), and Pradhan Mantri Gram Sadak Yojana (PMGSY) the pace of concrete pavement construction has increased recently. This is because concrete pavements are economical in life cycle cost and known to perform better with minimum maintenance. The concrete pavement can serve upto its design service life and even beyond if timely repairs are undertaken. Load transfer mechanism of the concrete pavement is through beam action and accordingly the concrete pavements are expected to perform relatively better than flexible pavements on weak sub grades, as these can bridge small soft or settled areas of sub-grades. The concrete pavement performance in high rainfall areas is found better than flexible pavement due to high resistance to water penetration. Similarly in hilly terrain, concrete pavement is able to resist impact load and abrasion due to braking and acceleration in a better way than flexible pavement. Design of concrete pavements is fundamentally governed by the flexural strength instead of compressive strength because the wheel load causes the concrete slab to bend which induces bending stresses. Therefore the critical stresses are flexural stresses rather than the compressive stresses in the concrete pavement. IRC:SP:83, "Guidelines for Maintenance, Repair and Rehabilitation of Cement Concrete Pavements" was first published in the year 2008 and used by the various stakeholders. Meanwhile, lot of advancement has been taken place in the technology, machinery and the material as well as feedback was received from the Industry, so need was felt to revise this document. Accordingly, the task of revision of this document was taken by the Rigid Pavements Committee (H-3) during the tenure 2015-17. The revised draft was prepared by the subgroup comprising Shri R.K. Jain, Dr. V. Ramachandra, Shri Anil Trivedi and Shri Binod Kumar. Other than the H-3 Committee members, valuable inputs were received from the officers of S&R Zone of the Ministry of Road Transport and Highways. The draft was deliberated in several meetings of H-3 Committee and was finalized in its meeting held on 9th September, 2017. The revised draft was placed before the Highways Specifications and Standards Committee (HSS) in its meeting held on 24th October, 2017. The HSS Committee approved the draft subject to the consideration of the observations of members. The draft document after carrying out the modifications was considered and approved by the Executive Committee of IRC in its meeting held on 2nd November, 2017 for placing before the Council of IRC. The Council in its meeting held on 3rd November, 2017 at Bengaluru considered and approved the document for printing.

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1.2 Concrete pavement has flexural strength to withstand traffic and environmental load. Concrete gains strength with age and under normal conditions may gain, in 90 days, about 10 per cent strength over its 28 days strength. The design and construction of rigid pavements is covered in the following IRC publications:

- IRC:15 - "Code of Practice for Construction of Jointed Plain Concrete Pavements"
- IRC:43 - "Recommended Practice for Plants, Tools and Equipment Required for Construction and Maintenance of Concrete Roads"
- IRC:44 - "Guidelines for Cement Concrete Mix Design for Pavements"
- IRC:57 - "Recommended Practice for Sealing of Joints in Concrete Pavements"
- IRC:58 - "Guidelines for the Design of Plain Joint Rigid Pavements for Highways"
- IRC:117 - "Guidelines for the Structural Evaluation of Rigid Pavement by Falling Weight Deflectometer"
- IRC:SP:17 - "Recommendations about Overlays on Cement Concrete Pavement"
- IRC:SP:62 - "Guidelines for Design and Construction of Cement Concrete Pavements for Low Volume Roads"
- IRC:SP:76 - "Guidelines for Conventional and Thin Whitetopping"
- MoRT&H - "Specifications for Road and Bridge Works" (Fifth Revision)

1.3 The Figs 1.1 to 1.3 depict broad arrangements of three main types of concrete pavement i.e. Jointed Plain Concrete Pavement (JPCP), Jointed Reinforced Concrete Pavement (JRCP) and Continuously Reinforced Concrete Pavement (CRCP). Fig. 1.4 depicts a typical cross-section of rigid pavement. These Figures are given to facilitate better appreciation of the different types of rigid pavements and associated distresses.

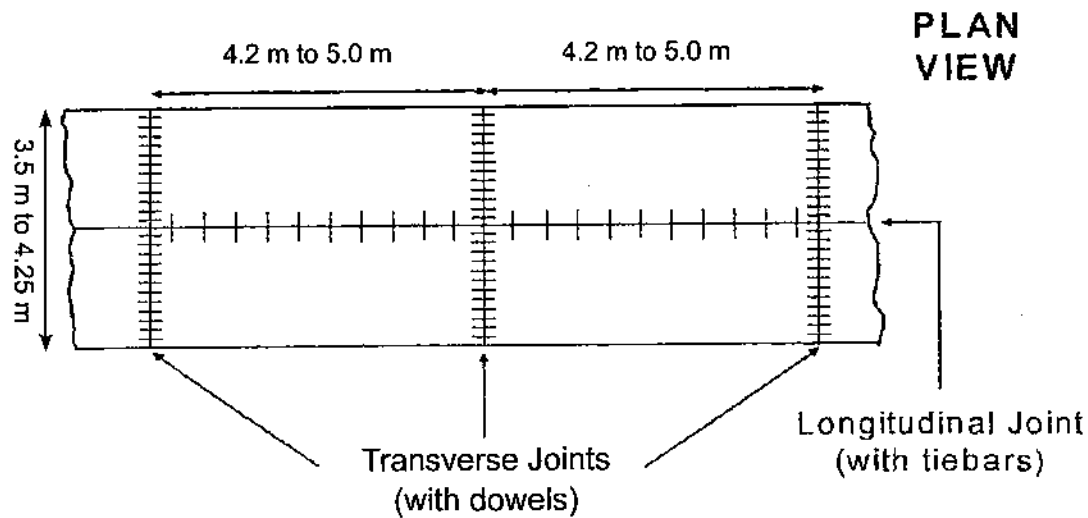


Fig. 1.1 Jointed Plain Concrete Pavement (JPCP)

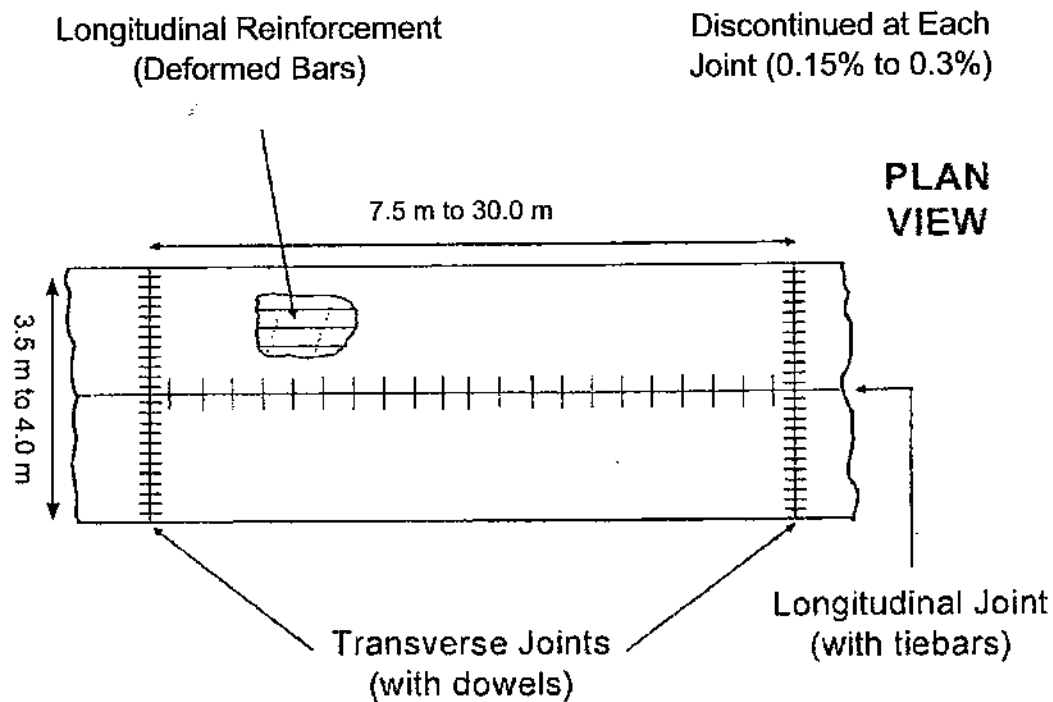


Fig. 1.2 Jointed Reinforced Concrete Pavement (JRCP)

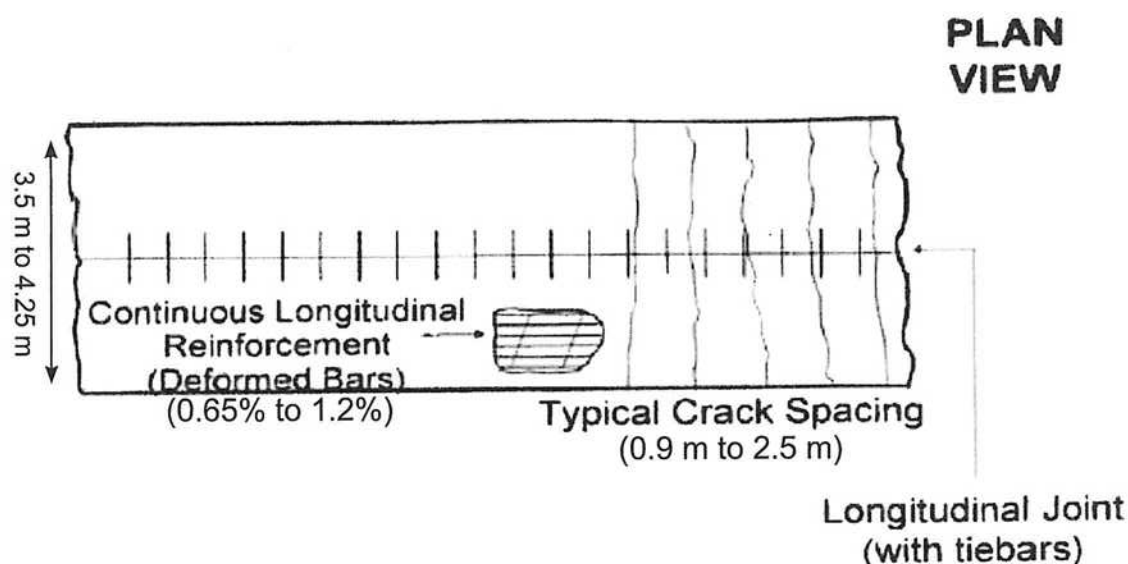


Fig. 1.3 Continuously Reinforced Concrete Pavement (CRCP)

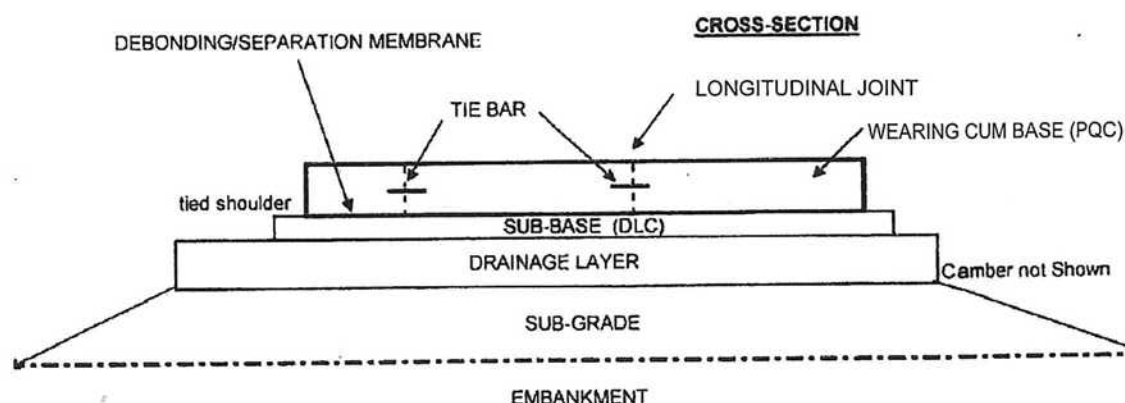


Fig. 1.4 Rigid Pavement Typical Cross-Section

1.4 The concrete pavement slab expands with the rise in temperature and contracts with fall in temperature. Concrete slabs accordingly tend to curl and warp due to the change in temperature and moisture gradient across its cross-section. The changes in temperature and relative humidity causes concrete pavement to crack at regular interval. Keeping this in mind, contraction joints are provided at designed intervals to take care of the expected cracking. Contraction joints provided are thus especially for crack control to ensure that cracking in concrete slabs does not take place randomly, at other locations except at the contraction joint locations. **Fig. 1.5** shows a contraction joint after crack developed under the initial saw cut. It is presumed that if contraction joints are properly located, designed and constructed, cracks at other locations will not take place. However, due to various factors including deficiencies like inappropriate selection of materials, lack of timely and adequate curing, delayed joint cutting, and other construction deficiencies etc., uncontrolled (random) cracks in the concrete pavement do take place at undesigned locations. Faulting, scaling, loss of texture etc. are other types of distresses which are normally encountered in concrete pavements. These distresses are mainly due to improper functioning of joints, settlement of sub-grade, loosening of tie bars and improper construction workmanship.

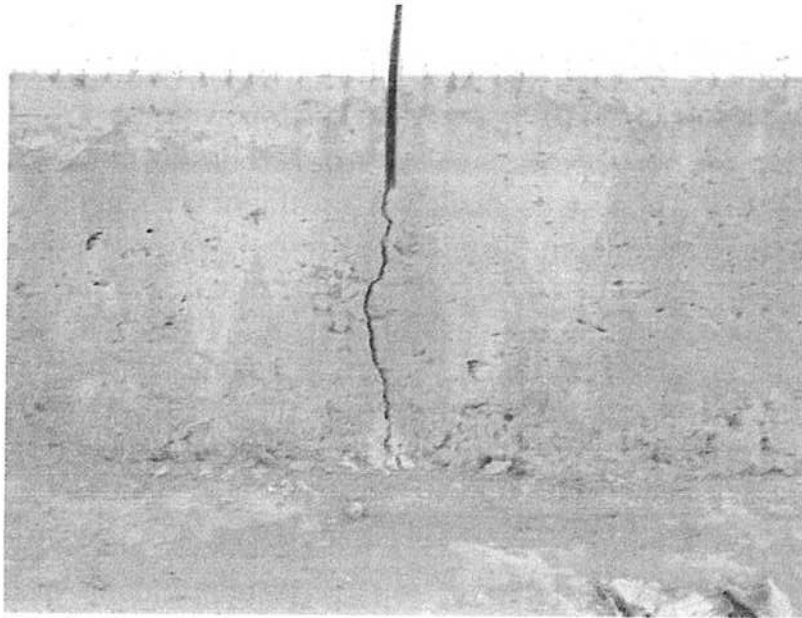


Fig. 1.5 Crack Induced under Saw Cut at Contraction Joint

1.5 Cracks are not uncommon to concrete construction and, therefore, minor shallow cracks need not be viewed as a serious problem. Many cracks can be restored easily to a condition that will serve for the design life of the pavement. In some cases, no repair may be required, while in others some preventive repairs like resealing, retexturing will be sufficient. Only deep structural cracks are a matter of serious concern for which repair methods are available. These guidelines apart from suggesting various repair techniques are also aimed to offset the impression that the repairs of the concrete pavements are something impossible and therefore, their construction should be avoided.

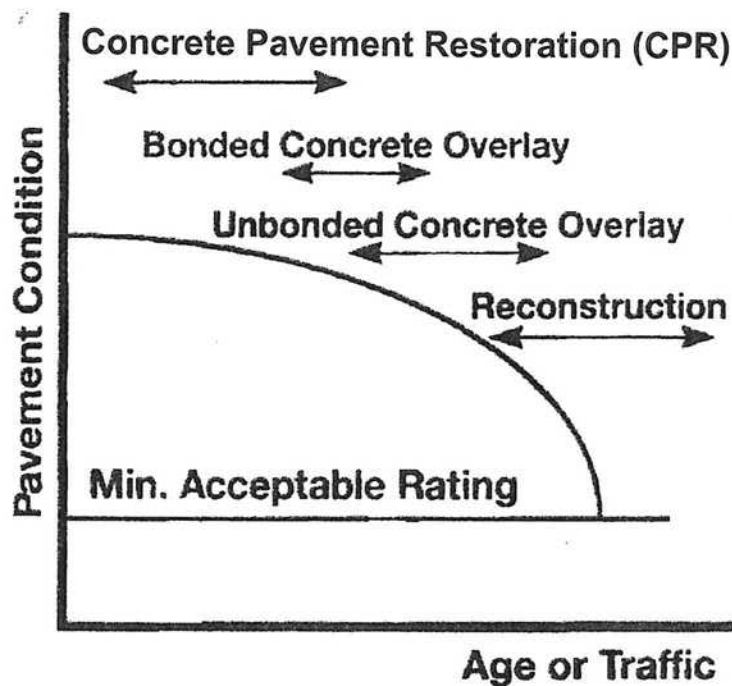


Fig. 1.6 Maintenance Strategy of Ageing Pavements with Level of Deterioration
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1.6 Scope

1.6.1 All pavements deteriorate with time. The rate of deterioration of concrete pavement is comparatively much slower than the flexible pavement. The concrete pavements are therefore expected to have a longer service life. **Fig. 1.6** indicates the typical treatment which may be considered with the age and condition of pavement. The techniques of assessment, repair and rehabilitation presented are for old concrete pavement during its normal service life. New concrete pavements should be laid with utmost care so that no distress or defect is observed during construction. In the case of concrete pavements, some distresses at a few isolated locations however, do take place immediately after or during an early stage after completion. If these isolated distresses are rectified well in time, then longer life of the concrete pavement is assured without much need of detailed periodic maintenance/rehabilitation. Preservation of concrete pavements, therefore, can be broadly classified into three categories:-

- (i) **Concrete Pavement Restoration (CPR) Techniques** - Repair and maintenance operations without any overlay
- (ii) **Rehabilitation** - Strengthening involving overlay options.
- (iii) **Reconstruction** - Undertaken after the end of service life or due to severe distresses in longer stretches due to faulty design/construction.

1.6.2 With proper design, construction and maintenance, a concrete pavement can give a useful service life of more than 30 years without any significant rehabilitation/reconstruction. Concrete pavement repairs/maintenance involves a series of engineering techniques which are used to repair the isolated areas of distress. Broadly such repairs theoretically do not enhance the structural capacity beyond the designed life of a concrete pavement. In reality such repairs, however, do extend the service life of the pavement. Timely repair by adopting CPR techniques is quite cost effective and helps to avoid costly rehabilitation/reconstruction later on.

1.6.3 Treatment depends on the wear characteristics. **Fig 1.5** shows typical methods that can be applied against pavement age. They range from repairs under Concrete Pavement Restoration (CPR) to overlays to complete reconstruction. Repairs are generally classified as to whether an overlay is used or not.

1.6.4 There could be situations where one or more repair techniques may be required to be used together to mitigate distresses. In some cases, where more than one repair technique is required to rectify the defects/distresses, these will be executed in a proper sequence to ensure the effectiveness of such repairs. Repair and maintenance strategies suggested in these guidelines are basically intended for old pavements of which defect liability period has expired. Guidance may be taken for the preparation of the contract clauses for new construction for which defect liability period is not yet over. However, the contractual clauses for new construction will prevail irrespective of the recommendations in these guidelines (Refer Para 5.3). These guidelines address the need for cost effectiveness and consideration of lane closure problems encountered during the operation phase which normally occur much after the construction phase. These guidelines are primarily focused on repair/maintenance of the concrete pavements through CPR techniques.

2 DEFINITIONS

2.1 General

The main types of maintenance required in respect of cement concrete pavements are as follows:

- (a) **Routine Maintenance:** Routine maintenance may be defined as those treatment that are applied to a pavement in order to keep the pavement functioning properly. As such routine maintenance is sometime called 'reactive maintenance'. This suggests that it is a work that is performed as a reaction to a specific distress. Routine maintenance is performed on pavement as they begin to show sign of deterioration, but is generally considered to be a wasted effort on pavement that are severely distressed.
- (b) **Programmed Maintenance:** It covers works undertaken to arrest deterioration and restore the asset to its original condition. Works are programmed in advance and defined to delay further deterioration. It normally includes work such as resealing the defective joint with sealant, cross-stitching, partial depth repairs, full depth and diamond grinding to remove faults in the rigid pavement.
- (c) **Rehabilitation and Strengthening:** It refers to programmed works that are undertaken to structurally restore the condition of a road section to impart further design life to carry future expected traffic loads. The works upgrade the road to current design standards. It includes work like diamond grooving for restoring surface texture, slab stabilization, reconstruction or application of an overlay to rectify structural deficiencies in the pavement, retrofitting of dowel bars and tie bars wherever needed.
- (d) **Emergency Repairs:** It covers responding to complaints or emergencies.

The repairs are usually performed by skilled (sometimes specialist) labour.

2.2 Terms and Definitions

Different terminology used in these guidelines will be read in accordance with the following definitions/abbreviations:

Blowup or Buckling	Compressive failure in which there is either upward movement of both or one slab (>4 mm) or shattering of one or both slabs at a joint or a crack.
Bump	Local areas at a higher level than the pavement profile.
Composite Pavement	A pavement consisting of both flexible and rigid layers with or without separating granular layers.
Corner Break Cracks	Diagonal full depth crack that intersects the corner joints at less than half width of the panel.
Corner Crack	Cracking that extends diagonally across corners (generally within 600 mm of the corner).

Crack along joint	Initial phase of spalling, crack intersects the joint at an angle or travels parallel to it.
Crow foot or Y shaped cracks	Deep shrinkage cracks (more than 25 mm) resulting from excess of bleeding water or water basins on the top surface of the slab.
Crazing (Map cracking)	Development of a network of fine random cracks or fissures on the surface layer. These cracks are rarely more than 3 mm deep and more noticeable on steel troweled surfaces.
Diagonal Cracks	Linear straight crack that extends diagonally across the slab.
Alkali-Aggregate Reaction Cracks	Family of closely spaced, crescent shaped fine cracks that initiate at slab corner/joints/cracked corners and run close and parallel to slab edges and result from chemically reactive aggregates and higher alkali content in cement. Cracked areas are usually darker in color. The cracking generally starts at the slab bottom and moves upward.
Fine/Hairline Cracks	Shallow surface cracks without any pattern which have an unspalled width of less than 0.2 mm at the surface of the slab
Longitudinal Cracks	Linear cracks running approximately parallel to the pavement centre line.
Alligator cracking	Cracks forming a rectangular (map) or irregular polygonal pattern (like an alligator skin).
Narrow crack	A crack which has an unspalled width of up to 0.5 mm at the surface of the slab.
Multiple Cracks	Multiple connecting cracks which are not in a straight line.
Medium Cracks	A crack which has an unspalled width of between 0.5 mm and 1.5 mm
Parallel Cracks	Usually fine cracks forming a family, more or less parallel to one another
Plastic Shrinkage Cracks	Plastic shrinkage cracks are those which appear on the surface of concrete before it has hardened. These cracks randomly located in the concrete are usually parallel to one another, and are few centimeters in length.
Reflection Crack	A crack in an overlay which occurs over a crack or a joint in the underlay.
Transverse crack	Linear cracks running at approximately right angles to the pavement centre line.
Wide crack	A crack which has an unspalled width exceeding 1.5 mm at the surface of the slab.
Working crack	Transverse crack extending full width of slab with depth (d) Greater than half the slab depth (D/2) which artificially create joint location.
Curling or warping	Curling or warping is distortion of the pavement slab from its proper plane into a curved surface caused by differential expansion or contraction resulting from a difference in temperature or moisture gradient between the top and bottom of slab. Fig. 2.1 illustrates distortion of pavement slab under different temperature and moisture gradients.

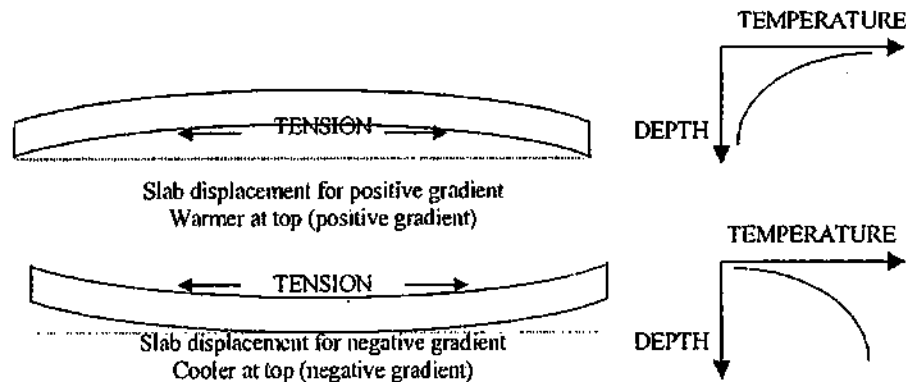


Fig. 2.1 Distortion of Pavement Slab under Different Temperature Gradient

Damaged Surface	Hardened surface deeply abraded or otherwise damaged following accident, or by vehicle tracks or metal wheels.
Depression	Localised sections/areas at a lower level to the normal pavement profile. This usually happens due to inadequate care at the time of laying.
Diamond Grinding (Cutting)	Diamond grinding is pavement preservation technique that corrects variety of surface imperfections. It uses a series of diamond tipped saw blades gang-mounted on a shaft for correcting irregular surfaces in concrete pavement that are commonly caused by faulting, curling and warping of slabs. This is also applied to the pavement surface to restore skid resistance.
Divided/Broken/ Shattered slab	Cracks in different directions dividing a slab in a number of pieces. Such cracks may intersect and may also converge in a point. In case of shattered slab the pieces are not less than four in number.
Dowel Bar Retrofit	Method for providing/restoring load transfer under the wheel paths in an old with/without doweled pavement or transversely cracked concrete slabs by installing dowels into slots cut into the pavement surface so as to extend the service life of the pavement slab.
Dowel Socketing	Loosening of dowel bars, which leads to load transfer. Improper installation of dowels leading to enlarging of dowel-cavity and resulting in loss of load transfer and spalling of concrete.
Drop off	Settlement between traffic lane and bituminous/soft shoulder following erosion or wear or secondary compaction of shoulder by traffic. The shoulder is at a lower level than the concrete pavement.
Faulting (or stepping)	A difference in elevation across a joint or crack usually associated with undoweled JPCP. Usually the approach slab is higher than the leave slab due to pumping. Faulting is noticeable when the average faulting in the pavement section reaches 4 mm or more. Diamond grinding or other rehabilitation measures should be considered for removal of faulting.
Foreign Matter	Foreign incompressibles like aggregates usually impregnated in the joint/joint sealant that may initiate spalling or locking of transverse or longitudinal joints.

Full depth repair	Repair involving the replacement of part or whole slab panel to the full depth of the slab.
Functional characteristics	Characteristics of the pavement which are important to users, including safety and riding comfort.
Heave	Heave is an upward swelling of soil exerting pressure on upper layers causing localized failure.
Impressions	Impressions that may be associated with depressions left in fresh concrete, by movement of animals/vehicles/bicycles.
International Roughness Index (IRI)	The international roughness index is obtained from measured longitudinal road profile. It is calculated by using a quarter – car vehicle mathematical model expressed as unit of m/km or mm/m.
Intervention level/standard	Maximum permissible tolerance level at which a defect is to be promptly scheduled for rectification.
<u>Joints:</u>	
Longitudinal Joint	Sawn or formed joint parallel to the centerline of pavement intended to relieve stresses due to transverse warping and for uneven settlement of the subgrade. Usually placed between lanes, to allow construction in convenient width.
Transverse Joint	Sawn or formed joint normally placed at regular interval at right angles to the centre line. Transverse joints consist of expansion joints, contraction joints and construction joints.
Construction Joint	Full depth butt joints placed wherever construction operations require to prevent a cold joint forming. Usually when paving operations stop for more than initial setting time or at the end of a day's paving.
Contraction Joint	Sawn or formed joint normally placed at regular intervals to permit the slab to contract and intended to relieve tensile stress in the concrete and to so prevent formation of irregular cracks in the slabs. The joints are of groove type, about 1/3 rd to 1/4 th depth of the slab so that cracks forms below the groove.
Expansion Joint	Butt joint which provides space in concrete to allow for expansion of slabs caused by the increase in mean temperature as compared to the temperature at the time of laying the concrete slab. They relieve compressive stresses due to expansion, as also those due to contraction and warping.
Loss of fine Aggregate/exposed and polished coarse aggregate	Fine aggregate loss around the coarse aggregates that show a rounded polished surface.
Loss of surface texture	Loss of surface texture is a measure of loss of skid resistance of concrete pavement surface. With time the texture gets abraded. This is measured by following two methods: <ul style="list-style-type: none"> (i) Sand Patch Method (for broom/brush texturing) (ii) British Pendulum Tester (for all kind of texturing)

Manhole or inlet failure	Cracking and/or faulting following restrained thermal movements around a manhole or inlet.
Overlay	An overlay is a layer of designed thickness over the existing pavement.
Bonded overlay	A thin concrete overlay in direct contact and adhering to the existing concrete which provides increase in the pavement structure. Used to correct functional or structural deficiencies.
Unbonded Overlay	A thick concrete layer on the top of an existing concrete pavement uses a separation interlayer to separate the new from old/existing concrete.
Whitetopping	A rehabilitation Technique associated with asphalt pavements comprising a thin concrete overlay placed directly over and bonded/unbonded with the existing asphalt surface. Not applicable to concrete pavements. For more details, refer IRC:SP:76
Partial depth repair	Replacement of damaged concrete after vertical saw cuts are made in a regular rectangular shape in the upper 1/3 rd depth of the slab.
Patching	Removal and replacement of an area of pavement with new material.
Joint Locking	The inability of the joint or crack to open and close with temperature/moisture changes.
Performance Standard	The performance standard defines the minimum level at which of the facility is to be maintained and operated for the safe passage of traffic.
Popout (Small Hole)	Small hole left in the pavement surface by oversized particles of soft aggregates, clay lumps or other soft/foreign materials getting mixed in the concrete rising to the top and breaking loose under traffic. Normally 25 mm to 100 mm diameter and 10 mm to 50 mm deep.
Polished Surface (Glazing)	Surface that has become flat and polished following the wearing away of the mortar over coarse monomineral or soft aggregates.
Pothole	Large hole in the pavement surface generally larger than 150 mm (diameter) x 50 mm (deep) resulting from loss of pavement material under traffic or environmental conditions.
Punchout	Partial area of a slab broken out by several cracks particular to continuously reinforced concrete slabs.
Pumping	Ejection of fine grained material and water from underneath the pavement through joints, cracks or pavement edge caused by the passage of vehicle over the slab.
Ravelling	Loss of fine aggregates from matrix and hardened cement paste/laitance from the surface through abrasion that may or may not have been previously cracked.
Rehabilitation	Structural enhancement that extends the service life of an existing pavement and/or improve its load carrying capacity.
Roughness	Term used for describing the unevenness/riding quality of the pavement as a whole. It is different from texturing for skid resistance.

Scaling	Peeling off the upper part of slab surface (5 mm to 15 mm) following Cracking or improper surface finishing.
Sealant	A material that is applied as a liquid that has adhesive and cohesive properties after curing used to seal, joints and cracks against the entrance or passage of water and or other debris.
Hardening (Oxidation) of Compression Seals/ Sealants	Overdue replacement of sealant that got hardened by oxidation or action of UV rays.
Lack (Absence) of Sealants	Either sealant was not provided or was lost.
Loss of Bond to Slab Edges	Sealant is no more adhering to slab edges, (walls of groove) allows ingress of water and debris.
Overbanding	Overfilling of crack or joint so that a thin layer of sealant spreads onto the pavement surface.
Stripping/extrusion of Sealants	Stripping/pulling out of portions of sealant, loss of bond from walls of joint groove.
Separation	Existing joint or crack widens; contact and friction of both section is lost.
Slab	The hardest concrete within the jointed area (Transverse and longitudinal), typically 4.2 m - 5.0 m (long) x one lane (wide).
Terminal slab	Last slab before the deck slab or approach slab (IRC:15).
Transition Slab	Last slab which is laid in steps and partly overlaid with flexible pavement (IRC:15).
Shattered slab	Cracking in all directions at interface with the longitudinal or transverse joint.
Spalling	Cracking and breaking off or chipping off the upper corner of the joint or crack that may extend to a certain lateral distance.
Deep spalling	Multiple cracking and breaking away of concrete adjacent to the joint, often semi-circular in plan and emanating down to the centre of the slab and sometimes deeper.
Shallow Spalling	The breaking or eroding away of concrete within the depth of the joint groove.
Spalling of joints (Transverse/ Longitudinal)	Cracking, breaking, chipping or fraying of slab edges within 300 mm from the face of the transverse/longitudinal joint.
<u>Stitching</u>	
Cross- Stitching	Straight normally 12 mm dia. high yield strength deformed bars placed in holes drilled diagonally alternating across a crack (30 degree approx.) at a predetermined spacing and the holes refilled with epoxy resin.

Stapling	U-Shaped normally 16 mm dia high yield strength deformed bars placed horizontally in slots cut 25 mm - 30 mm wide into the slab and the slot refilled with high performance/high strength cement mortar/epoxy mortar.
Structural Characteristics	Structural adequacy of the pavement in relation to its ability to carry future traffic.
Surface Evenness	The roughness of pavement surface is commonly designated as Unevenness Index Value and is expressed in surface roughness and is measured by Bump Integrator (BI). This is expressed in mm/km. Permissible limits shall be as prescribed in IRC:SP:16-2004 in units of "mm/km".
Warping	The distortion or displacement of the pavement from its proper plane into a curved surface caused by variation in moisture & temperature.
Design Extension	This is percentage stretchability of sealant without getting damaged/broken.

3 TYPES AND CAUSES OF DEFECTS

3.1 Distress Identification

A site condition survey once a year, preferably in the beginning of monsoon season should be undertaken to assess the existing pavement condition and to identify the pavement distresses. Such site condition surveys should aim at two objectives:

- (i) To determine the root cause of pavement's distress.
- (ii) To track the rate of progression of the distress leading to pavement deterioration.

Repair techniques discussed in these guidelines, except those of full depth repair, may not be effective, if the rate of pavement deterioration is relatively fast. In case of a fast rate of deterioration particularly in continuous long stretches, the rehabilitation options may be considered along with repair option and appropriate decision taken as per specific site conditions. Determining the root cause of failure, if possible, helps in identifying the appropriate repair techniques/strategies including the combinations thereof. The Chapter-4 describes in detail the different types of distress identification/assessment surveys. It is important to record both the severity and extent of each distress during condition survey undertaken. In case, it is felt that non-destructive and/or destructive testing are required to assess the structural problems, as the same are not adequately determined through visual inspections, then such testing should be undertaken subsequently.

3.2 Distress Types

Distresses in concrete pavements are either structural or functional. Structural distresses primarily affect the pavement's ability to carry traffic load. Functional distresses mainly affect the riding quality and safety of the traffic.

3.2.1 Structural distresses

All cracks are not structural cracks. Any uncontrolled/random crack like longitudinal, transverse, diagonal, intersecting cracks that extends through the depth of the slab ($> D/2$, where 'D' is depth of PQC slab) is to be considered as a structural crack. Structural cracking is often caused due to excessive loading, long joint spacing, and shallow or late sawing of joints, restraint at base or edge, due to joint lock-up, inadequate thickness, material related problems etc. Often reasons for structural cracking could be pumping of fines from the sub-grade or the sub base, excessive warping of the slab, subsidence of utility trench, excessive temperature stresses and moisture content. Structural cracks unless repaired effectively reduce the load carrying capacity of the pavement and adversely impact the designed service life of the pavement. Use of proper construction techniques and traffic load controls can reduce/avoid structural cracks.

3.2.2 Functional distress

These distresses do not necessarily reduce the load carrying capacity of the pavements but affect the riding quality, and safety. Roughness, loss of surface texture or any other surface related defects, problems like faulting, scaling, ravelling and popouts etc. fall under this category.

3.3 Common Defects and Distresses in Concrete Pavements

These could be due to poor quality of materials/workmanship/design defects and environmental causes.

3.3.1 Manifestation of distress in cement concrete pavements may be classified in the form of:

3.3.1.1 Cracking

- (a) Plastic shrinkage cracks
- (b) Crow Foot or "Y" shaped cracks
- (c) Edge cracks
- (d) Corner cracks breaks
- (e) Transverse cracks
- (f) Longitudinal cracks
- (g) Diagonal cracks
- (h) Durability "D" cracking
- (i) Punchouts

3.3.1.2 Surface Defects

- (a) Pop-outs/Small holes
- (b) Animal/Wheel impressions
- (c) Scaling
- (d) Ravelling
- (e) Deep abrasion/scooping of surface (following accident)
- (f) Polished aggregates/glazing/smooth surface

3.3.1.3 Joint Defects

- (a) Spalling
- (b) Sealant failure and/or loss
- (c) Faulting at joints
- (d) Separation at joints

3.3.1.4 Other Miscellaneous Defects

- (a) Blowups
- (b) Pumping
- (c) Patch Deterioration
- (d) Drop off

The broad causes for common type of defects are given in **Table 3.1**.

3.4 Causes of Common Distresses

3.4.1 Timing of sawing the joints

3.4.1.1 Understanding the causes of pavement distress is essential for providing appropriate effective repair and developing maintenance strategies. Contraction joints are provided in the concrete pavement to control the formation of uncontrolled cracks in the concrete pavement. But early uncontrolled cracks do occur for a variety of reasons. It is therefore important to identify the correct causes so that appropriate cost effective method for rectification is selected.

3.4.1.2 Timing of joint cutting is very critical. Determination of appropriate timing of sawing requires experience and is also a site specific decision. It depends upon factors like, ambient temperature, wind velocity relative humidity, type of aggregates used in concrete and rate of strength gain etc. Ref. IRC:15

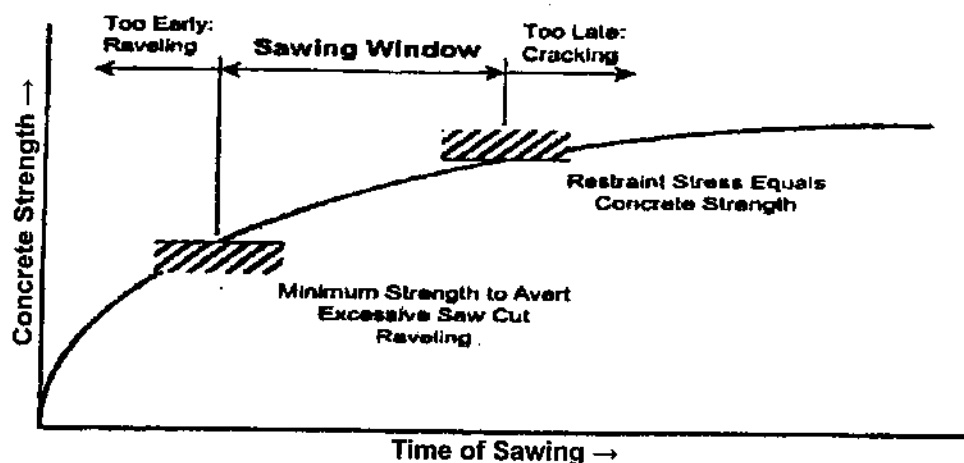


Fig. 3.1 Sawing Window

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3.4.1.3 There is a time range during which the activity of sawing should be completed. This time range is known as sawing window. **Fig. 3.1** depicts this sawing window. Experienced saw operators rely on their judgment and scratch test to decide as to whether the concrete is ready

for sawing. Concrete surface can be scratched with a nail or knife blade to examine how deep the impression is formed. As the surface hardens, the scratch depth decreases. In general, if the scratch removes the texture, sawing should not be undertaken as it will be a case of too early sawing. An experienced crew can always fine-tune the optimum sawing timing. Sawing to appropriate depth is very important and shallow depth sawing will lead to random cracking. The appropriate sawing depth is between $1/4^{\text{th}}$ to $1/3^{\text{rd}}$ of PQC thickness.

Too early sawing leads to unacceptable ravelling (**Fig. 3.2**) and too late sawing leads to uncontrolled/random full depth cracking. Uncontrolled/random full depth longitudinal cracking often occurs due to too late sawing. An early entry dry saw, if applied to a depth of 0.2 times the thickness of the PQC or 25 mm will avoid random cracking. Sawing should not be initiated when the compressive strength of the concrete is less than 2 MPa and should be completed before it attains the compressive strength of 7 MPa. These figures are indicative only. The actual timing will depend upon ambient temperature, wind velocity, aggregate types, humidity etc. Another way is to saw alternate panels to begin with. This will help to complete the sawing operation within the sawing window range. The left out panels should be sawed subsequently. It should be ensured that these alternate panels are not left unsawed inadvertently. This type of sawing is known as skip-sawing technique. The sawing should be started when the pavement is able to bear the weight of crew and saw-machine. It is usually 6-18 hours depending upon season i.e. summer and winter.

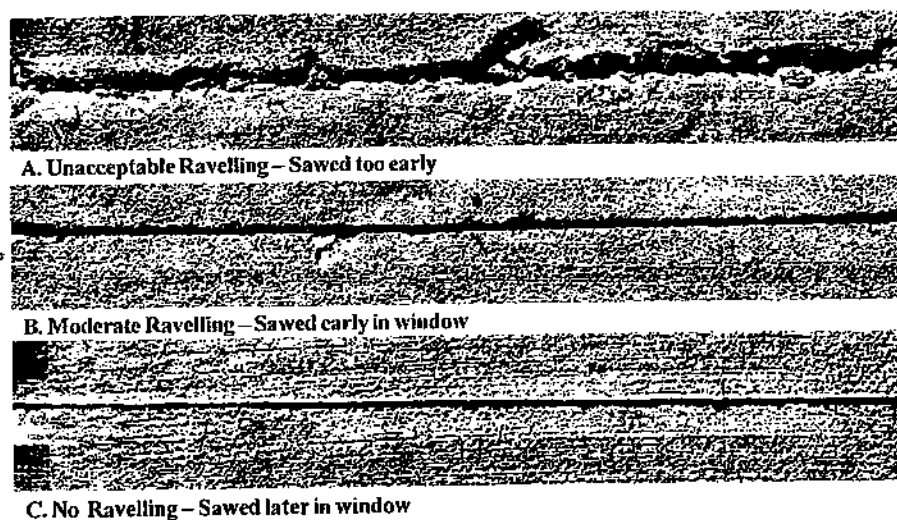


Fig. 3.2 Close up of Different Degrees of Ravelling Caused by Joint Sawing (ACPA)
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3.4.1.4 Plastic shrinkage cracking

It is important not to confuse cracks arising due to restraint of the concrete at early age due to misaligned dowel bars, improper joint spacing and timing of joint cutting with plastic shrinkage cracks. Plastic shrinkage cracks are tight, about 0.3 m to 0.6 m long formed in parallel group's perpendicular to the direction of the wind, at the time of paving. Plastic shrinkage cracking is a result of rapid drying at the pavement surface. The cracks normally extend down to a depth of about 20 mm - 30 mm. Adequate curing measures are necessary to prevent their occurrence. These cracks normally do not influence the overall performance of the pavement and can be repaired as described in Chapter 5. Misting/fogging after 2-3 hours minimizes all surface cracks.

3.4.1.5 Drying shrinkage cracking

Wider/deeper cracking is usually attributable to the drying shrinkage and restraint developed in the concrete due to inadequate joint spacing, improper saw cutting or misalignment of dowel bars. The optimum spacing of joints in a jointed concrete pavement depends on the slab thickness, sub-base stiffness and concrete strength. ACPA recommends a maximum joint spacing of 21 times depth of the PQC slab for concrete pavement constructed over dry lean concrete (DLC)/stabilized sub-base. Other agencies recommend even closer joint spacing, so as to maintain the ratio of slab length to the radius of relative stiffness less than 5. The equation 3.1 gives radius of relative stiffness. Pavement with long transverse joint spacing may otherwise develop full panel width deep cracks due to tensile stresses developed due to temperature curling.

$$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2).k}} \quad (\text{Ref: IRC:58}) \quad \text{Eq. 3.1}$$

Where, l = radius of relative stiffness, cm
 E = Modulus of elasticity of concrete kg/cm²
 h = Thickness concrete slab, cm
 μ = Poisson's ratio
 k = Modulus of sub-grade reaction kg/cm³

Where, it is necessary to repair/replace the sub-base, a separation membrane or two coats of a wax based bond breaker, shall be applied on top of the new DLC layer before reconstruction of the Pavement Quality Concrete (PQC).

3.4.1.6 Misaligned dowel bars

If the saw timing and saw cut depth are found adequate, cracking could still occur due to the misalignment of dowel bars. The misalignment of dowels can induce a crack away from a transverse joint, if the dowels physically lock two slabs together and restrain their contraction.

3.4.2 Traffic loading and environmental influences

The concrete pavements are subjected to stresses due to traffic loading and environmental stresses due to change in temperature and moisture conditions which can have the following effects:

3.4.2.1 Traffic related distress causes are the most widespread and frequent. They usually act in combination with climatic causes.

- Axle loads are responsible for fatigue and impact failure of the materials of different pavement layers including the pavement slab. They also originate structural cracking both shallow and full depth and vertical differential movements of the concrete slabs or faulting as well as lateral slab movement.
- Wear by traffic tires results in loss of texture and consequential functional distress of the pavement surface.

3.4.2.2 Temperature related distress of concrete slabs results from temperature variations and temperature gradients through the slab thickness.

- Thermal expansion or contraction is resisted by friction of the underlying layer and by the adjoining slabs. Compressive stress builds up during expansion that may originate cracking.

- Temperature gradients also initiate slab curling and loss of uniform sub-base support, which may lead to cracking including structural cracking.

3.4.3 Moisture decreases the bearing capacity of underlying layers, facilitates abrasion and internal erosion. Surface water ingress in the pavement structure shall be prevented by properly sealed joints and by timely sealing of cracks. However sealing materials deteriorate with time and properly designed and operational pavement sub-surface drainage shall be provided so that any percolating water does not remain entrapped within the pavement. If these conditions are not fulfilled and water is trapped in or between the pavement layers it will be subjected to high pressure and may be expelled under passing traffic loads carrying fine materials (pumping) in suspension that result from internal erosion of the pavement materials.

3.4.4 Run-off water may ingress in joints and cracks carrying with it foreign incompressible materials.

3.4.5 Repair cannot be durable if distress causes are not found and eliminated. One type of distress can generally result from several different causes. So careful observations and follow-up are required to discard certain causes and confirm some others. Mapping and rating of the distress type may be done adequately. In some cases it may happen that distress causes cannot be satisfactorily investigated until the pavement is excavated before carrying out the repair. The necessary excavation should be done at such locations.

3.5 Diagnosis of Defects

3.5.1 Causes of construction defects can be related to workmanship and work methods as described above, as well as equipment operating condition and adjustment and the properties of the materials.

3.5.2 Unexpected changes in climatic conditions (temperature, moisture, wind) may also originate defects and distress, when appropriate preventive action is not taken.

3.5.3 Construction records and diaries of line supervisors and managers should contain the most important/useful information to identify causes of defects. For example: ambient temperature, speed and direction of wind at the time of paving, time of joint saw cutting, inconsistencies in delivery and/or placing of the concrete, malfunctions of the equipment etc.

3.6 Diagnosis of Functional Defects and Distresses

3.6.1 Functional Performance of the pavement refers to characteristics of the pavement that are important to users. These characteristics primarily include safety (as measured by skid resistance testing by the British Pendulum or Mu-meter Test or texture depth as measured by the Sand Patch test) and riding comfort (as measured by profilograph or bump integrator and in some situations also by noise measurements).

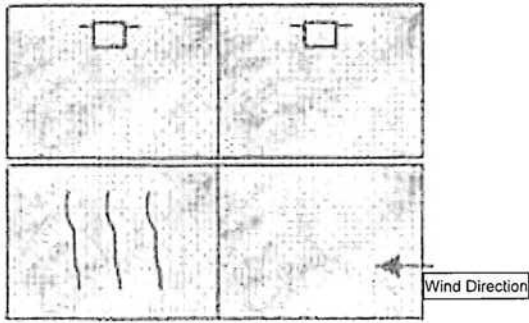
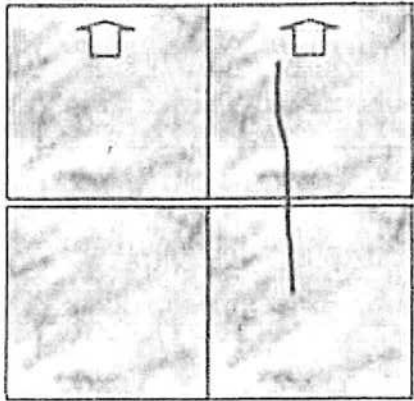
3.6.2 Surface Functional distress results from wearing of the pavement surface materials by traffic tyres and heavy abrasion from vehicle parts during breakdown/accident. Their causes can therefore be found in the volume of traffic, in tangential efforts applied by the tyres, like braking efforts and in the capability of the pavement surface materials to withstand such efforts with minimum wear under the prevailing weather conditions.

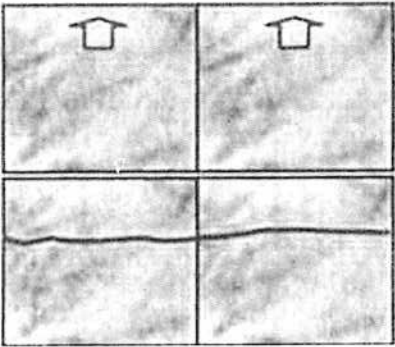
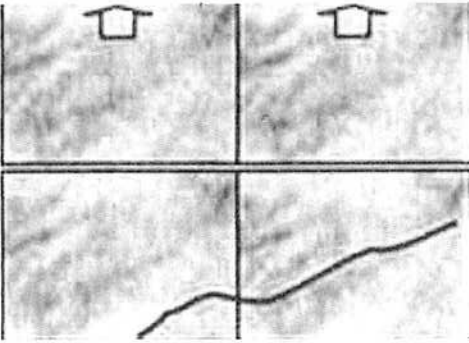
3.7 Diagnosis of Structural Defects and Distresses

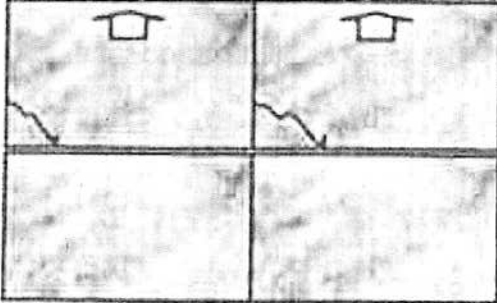
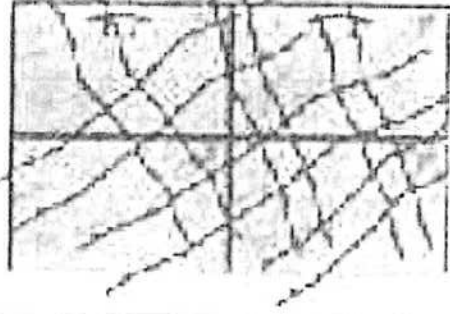
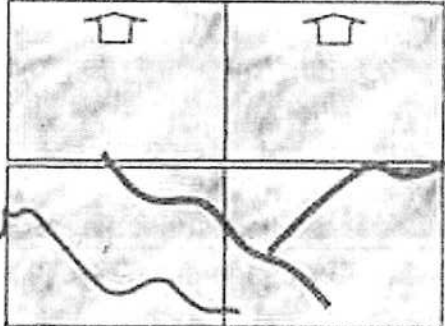
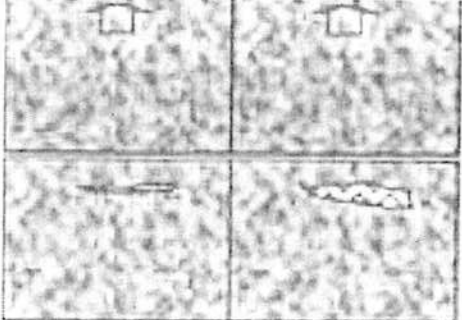
3.7.1 Structural performance refers to the structural adequacy of the pavement in relation to its ability to carry future traffic. Structural adequacy can be determined by performing distress surveys like deflection testing, nondestructive testing, and materials testing, after visual inspection.

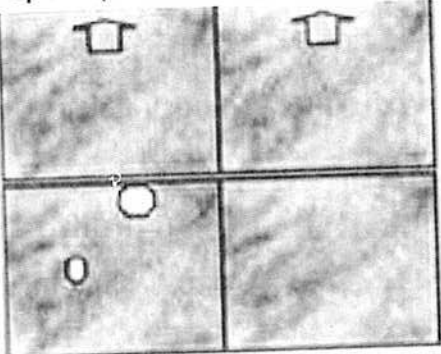
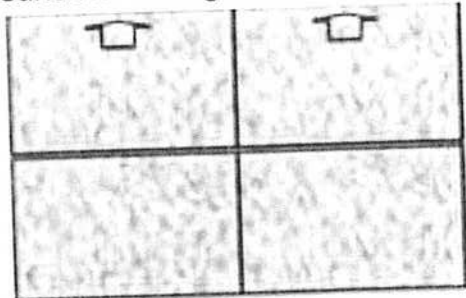
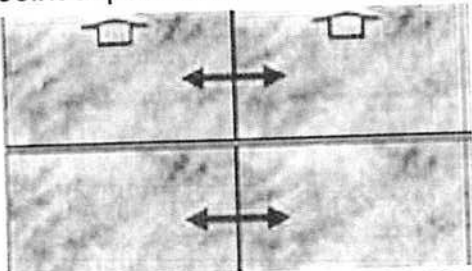
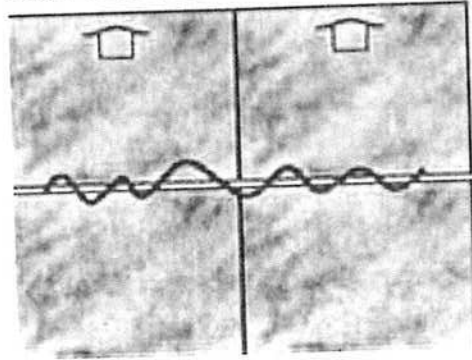
3.8 Table 3.1 gives the details regarding the common type of defects in the concrete pavements and their possible causes.

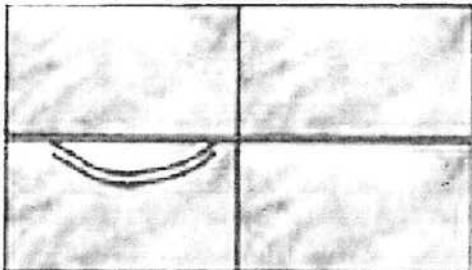
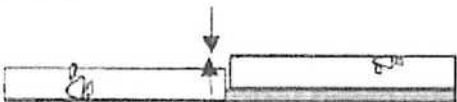
Table 3.1 Type of Defects and Causes

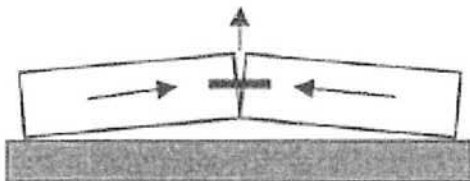
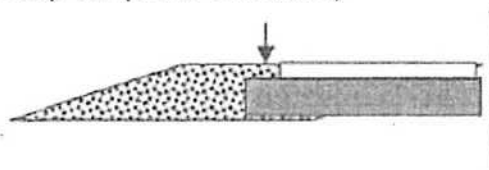
S. No.	Class and Type of Defects	Common Causes
1	Cracking	
	a) Plastic Shrinkage Cracks 	i. Drying shrinkage stresses in surface ii. Poor curing iii. Hot windy conditions iv. Excessive water at surface (bleeding)
	b) Longitudinal Cracks 	i. Excessive drying shrinkage stresses ii. Inadequate depth of joint or late joint sawing iii. Excessive joint spacing iv. Sudden/abrupt thermal and moisture gradient changes v. Downhill paving; cracks perpendicular to the direction of super elevation vi. Channelized or static heavy loading, viz. truck parking vii. Loss of sub-grade support, for instance poorly compacted sub grade viii. Settlement of embankment which leads to subsequent settlement of slabs ix. Different sub-base/sub-grade types having different modulus of elasticity and or moisture regime across the width of the cross-section x. "Vibrator trails" caused by malfunctioning or improper adjustment of vibrators on the paving machine

S. No.	Class and Type of Defects	Common Causes
	<p>c) Transverse Cracks</p> 	<ul style="list-style-type: none"> i. Tensile stresses developed in concrete are more than tensile strength of concrete ii. Excessive drying shrinkage stresses iii. Inadequate depth and/or late initial joint groove sawing iv. Excessive joint spacing or length l width ratio of slab More than 1.5 or length of unreinforced slab exceeds normal range 4.5-6.1 m. v. Misaligned, corroded, locked, burred on ends dowel bars vi. Crack at the end of the dowel bars; or locking of dowel bars, loose dowel bar sleeves, sleeves of poor quality. vii. Delays or interruption of concrete placing for more than 30 minutes viii. Excessive overloading ix. Sudden/abrupt thermal and moisture gradient stress changes x. Excessive sub base restraint xi. Settlement/poor sub-base support at localized area xii. Incorrect location of transverse joints at/over cross drainage structure/utility duct
	<p>d) Diagonal Crack</p> 	<ul style="list-style-type: none"> i. Excessive drying shrinkage stresses ii. Excessive thermal and moisture gradient stresses iii. Excessive joint spacing iv. Unstable sub-grade or loss of sub-base support (settlement of utility trench, etc) v. Excessive over loading vi. Frost action

S. No.	Class and Type of Defects	Common Causes
	e) Corner Breaks 	i. The same as diagonal cracks ii. Poor load transfer iii. Dowel bar restraint iv. Curling, thin slabs are particularly susceptible to this cause
	f) Alligator (Map) Cracking 	i. Coarse aggregate expansion ii. Chemically reactive aggregate iii. Weak concrete iv. Improper curing
	g) Multiple Structural Cracks 	i. Lack of sub-grade support ii. Excessive over loading iii. Weak concrete iv. End of service life
2.	Surface Defects	
	a) Ravelling Scaling 	i. Segregation at surface ii. Cracking or fine alligator cracks iii. Frost iv. Unsound or dirty aggregates v. Weak concrete (too much water, too much fine aggregate) vi. Inappropriate curing vii. Excessive Abrasion

S. No.	Class and Type of Defects	Common Causes
	b) Popout (Small Hole), Pothole 	i. Loss of contaminated or non-durable concrete pockets at surface ii. Lack of homogeneity, uniformity and consistency of the mix iii. Loss of aggregate from concrete surface: thermal expansion, freeze-thaw iv. Inadequate compaction
	c) Loss of surface Texture, polished surface/Glazing/Smooth Surface 	i. Movement of construction traffic at an early age ii. Wear and tear under high volumes of traffic particularly under wet or uncleaned surface iii. Poor texturing during construction iv. Soft and mono-mineral aggregates v. Frequent braking and turning sections vi. Non-durable concrete
3	Joint Defects	
	a) Joint separation 	i. Insufficient or incorrect tie bar installation in longitudinal joints ii. Shoulder movement iii. Downhill slipping of slabs on a steep gradient/super elevation iv. Slippage of tie-bars at sharp curves v. High Embankment/black cotton soil
	b) Joint Seal Defects 	i. Hardening (oxidation) or softening by ultra violet radiations ii. Stripping of joint sealant iii. Extrusion of joint sealant: overfilled groove, lack of incompressible caulking strip in bottom of groove, incorrect groove dimensions iv. Adhesion failure/loss of bond between walls of groove and sealant due to: inadequate preparation of groove, inadequate priming, inappropriate sealing material, semi-set/inadequately cured "cold" concrete, moisture in groove; slurry generated due to widening of groove sticking to the walls of groove

S. No.	Class and Type of Defects	Common Causes
		<ul style="list-style-type: none"> v. Pressing of small stones and other incompressible matter into the sealant vi. Embrittlement of joint sealant or cohesion failure due to inappropriate sealing material, incorrect groove dimensions, lack of bond breaking strip beneath the seal vii. Inadequate or no tooling to remove air bubbles viii. Inadequate curing before opening to traffic ix. Lack or absence of sealant x. Weed growth in the joints
	<p>c) Spalling at cracks or joints</p> 	<ul style="list-style-type: none"> i. Ingress of stones and other incompressible material into joint ii. Dynamic traffic loads at slab ends, mechanical damage iii. Weak concrete, poorly compacted or non-durable, particularly at construction joints iv. Failure or defects of dowel load transfer system v. Joints intersection vi. Slab overstressing
	<p>d) Faulting (or Stepping) in cracks or Joints</p> 	<ul style="list-style-type: none"> i. Along transverse joints or cracks: buildup of material under the approach slab or slab piece; ingress of water internal erosion and pumping ii. Warping or curling following either moisture or temperature gradients iii. Along longitudinal joints: settlement of sub-grade or shoulder drop off caused by heavy traffic iv. Differential settlement/support due to inadequate foundation/or growth of tree roots v. Reduction in/or lack of load transfer due to separation of slabs

S. No.	Class and Type of Defects	Common Causes
4.	Deformation	
	a) Blow Up or buckling 	i. Accumulation of incompressible material in the joints ii. Excessive expansion resulting from combined adverse thermal and moisture conditions iii. Wrong spacing of joints
	b) Drop-off (Lane shoulder) 	i. Wear and tear from stray and parked vehicles ii. Poor quality of shoulder material i.e. not suited for the purpose iii. Settlement of shoulder iv. Erosion of unpaved shoulder due to surface run-off in rainy season

4 ASSESSING MAINTENANCE NEEDS

4.1 General

4.1.1 The evaluation of the existing pavement condition is the most important part of the process of assessing the maintenance needs. The maintenance strategy will be determined according to the level of deterioration (refer Para 1.6.1 and **Fig. 1.6**). The characterization of the condition of the existing pavement largely determines the types of treatments to be considered. Characterization includes the types of distress, width and depth of crack/defect, percentage area affected; joint defects etc. (refer **Table 4.5**). Different evaluation tests and procedures are available for a complete and comprehensive evaluation of the existing pavement condition.

4.1.2 The maintenance needs should be assessed every year as part of the planning of the road maintenance program. It is recommended that an overall assessment of the maintenance needs be done on the basis of condition surveys which can take various forms such as:

- visual inspection and rating as per **Proforma 4.3**
- profile/faulting/roughness measurements, by Profilograph and Bump Integrator (BI)
- deflection tests; Falling Weight Deflectometer (FWD)
- friction/skid resistance tests by sand patch, British Pendulum and Mu-meter
- drainage condition survey
- Non Destructive Testing (NDT) Techniques like Ultrasonic Pulse Velocity, Impact Echo etc.

4.1.3 Additional testing and measurement will be required to collect specific data particular to the needs identified during the overall condition survey based on repair/rehabilitation alternatives

to be considered in the maintenance program. For example concrete material evaluation, base/sub base and sub-grade testing and drainage condition surveys. The frequency of such additional testing will depend on the age and extent of damage recorded in the overall condition survey. A review of the project records including plans, specifications, construction quality assurance/quality control records and general inspection notes will be helpful.

4.2 Pavement Evaluation Procedure

4.2.1 Road agencies around the world have developed a range of procedures for evaluation of the concrete pavements in their countries. US Federal Highway Administration (FHWA) has developed 17 standard procedures as given in **Table 4.1**. Relevant tests which are suitable to a particular site may be adopted for the evaluation of the pavement condition. Some of the commonly used procedures are indicated below:

- a) **Visual Condition Surveys** - Either manual or video/photographic-based procedures can be followed. Specific commentaries are provided to address special features related to concrete pavement distresses.
 - i. Visual rating is a simple method of inspecting the pavement for detecting and assessing the type and severity of the damage. In most instances, road inspections address all aspects of road condition, including the condition of shoulders, road drainage, road furniture etc., as well as the condition of the pavement.
 - ii. Visual condition survey may be conducted from a vehicle driving over the pavement or a manual survey conducted by walking or riding in cycle rickshaw along representative sections. Automated survey equipment are available and may be deployed for the purpose.
 - iii. Whilst there are various methods of visual rating adopted by different agencies over the world, an essential requirement is to inspect the concrete pavement on a regular basis and record the various maintenance needs kilometer-wise all along the length of the road in standard formats. **Proformae 4.1, 4.2, 4.3 and 4.4** are placed at the end of this Chapter. These proformae are suggestive/indicative in nature and could be suitably modified in field as per project specific requirement.
 - iv. Although slow and labour intensive, the manual condition survey is the most reliable. The best method to record location and extent of distress types in a manual survey is graphical (map) and tabular format. Typical examples for guidance are provided in **Proforma 4.1** and **Proforma 4.2** respectively. The different types of distress shall be rated and their degrees of severity noted in the forms at the places where they occur. The details may be further summarized in the standard format as recommended in **Proforma 4.3**.
 - v. Any type of distress or defect may be located at a certain pavement section and at a certain distance from the centre line. The same distress may extend in length between two sections across the transverse or longitudinal joints. It may extend laterally to the whole width of the carriageway or only to certain strips or areas. Such extension of distress should be carefully noted to study the extent of such distress.

- vi. The location and extent of the defect/distressed area are recorded as observed at the surface. Since internally deteriorated concrete below the surface can have larger extension than superficial observations may show, before marking the area to be repaired it is important to test the surrounding slab areas.
- vii. The actual extension of deteriorated concrete can be determined by "sounding", which is done by striking the surface with a rod or a hammer or by dragging a chain along the surface. This will produce a metallic ring on sound concrete and a dull/hollow sound on deteriorated concrete.
- b) **Deflection Testing** - This testing is an important part of any pavement evaluation plan. Key aspects are addressed such as the time of testing for concrete pavements, especially for joint and crack testing for Load Transfer Efficiency (LTE) and void detection.
- c) **Roughness Surveys** - This is to be done as per IRC: SP:16. Research has established that pavements constructed initially with low roughness level have relatively longer life.
- d) **Skid Resistance Survey** - There are three methods to assess roughness of the surface as suggested below:
 - i. **Sand Patch Method:** As per IRC:15, the value should be between 0.65 mm to 1.25 mm.
 - ii. **Measurement by British Pendulum Test:** The value of Skid Resistance Number (BPN) as per Transport Research Laboratory (TRL, Road Note No. 27), the value should be between 45 - 55 BPN (as per British Pendulum Test) in normal conditions. (Refer **Appendix E** for more details about the British Pendulum Test).
 - iii. **As per Mu - Meter:** Table 1 Appendix E gives the acceptable values for Skid Number 36 to 31 at different traffic (vehicle) speeds from 50 kmph to 110 kmph. (Refer **Appendix E** for more details about Mu-Meter)
- e) **Faulting Surveys** - The faulting of joint/crack is normally measured with a millimeter scale. However, advance equipment like Georgia Fault meter if, available may also use for measuring joint/crack faulting.
- f) **Core Testing** - The guidelines refers to standardized testing procedures by the Bureau of Indian Standards (BIS). Core samples may be used for strength testing, and modulus of elasticity testing. Petrographic as well as durability (materials related distress) testing may also be carried out with the core samples.
- g) **Ground Penetrating Radar (GPR) Testing** - Guidelines are provided that address ground GPR techniques relative to PCC pavement applications.
The GPR scanning technique could be used for in the following applications:
 - 1. Detection and mapping of underground services;
 - 2. Detection of of bedrock/boulders and cavities;
 - 3. Detection of underground structures such as trenches and tunnels
 - 4. Detection of sinkholes along roads and highways;
 - 5. Detection of water seepage/leakages;

6. Determination of concrete qualities mapping of defects;
 7. Detection of reinforcements positions and tendons/ducts profiles
- h) **Slab Curvature Measurement** - Curling/warping may be determined using the dipstick or by measuring slab deformation (deflections) at slab corners and at other locations using Linear Variable Differential Transformers (LVDTs) or dial gauges. Such testing may be needed in some cases to determine, if premature failure conditions (cracking, etc) are due to excessive slab curling and warping.
- i) **Drainage Surveys** - Drainage evaluation needs to be included as part of overall pavement evaluation, so as to assess any potential future problems caused by moisture and run-off especially where the average rainfall exceeds 500 mm per year. The moisture may penetrate the pavement through cracks or transverse/longitudinal joint due to delamination or oozing out of sealant from the walls of the groove. The condition and effectiveness of side drainage also require recording, particularly, before the monsoon period. The presence of rain cuts, piping and erosion of shoulders should also be recorded. Drainage condition survey data form is given in **Proforma 4.4**.

Table 4.1 List of Procedures for Pavement Evaluation

PROCEDURE NO.	TITLE
Overall Pavement Evaluation	
TP-1	Visual Condition Survey
TP-2	Deflection Testing
TP-3	Profile Survey
TP-4	Faulting Survey
TP-5	Slab Curvature Measurement
TP-6	GPR Survey
TP-7	Friction Testing
TP-8	Noise Measurement
Concrete Material Evaluation	
TP-9	Core Compressive Strength Testing
TP-10	Core Split Tensile Strength Testing
TP-11	Core Modulus of Elasticity Testing
TP-12	Core Petrographic Examination
TP-13	Material Related Distress Evaluation
Base/Sub/Base and Subgrade Testing	
TP-14	Base/Sub-base and Subgrade Material Characterisation
TP-15	Dynamic Cone Penetrometer Testing
Drainage Condition Survey	
TP-16	Overall Drainage Survey
TP-17	Corrosion Testing

(Source: Report No . FHW A-0 1-C-00080)

4.3 Functional Evaluation

4.3.1 The functional performance of a pavement refers to characteristics of the pavement which are important to the users, including safety (as measured by cleanliness and friction testing) and riding comfort (as measured by profile testing and noise measurements).

4.3.2 The measurement of irregularities (roughness) in the road surface can be used to indicate in physical terms the existing condition of the road and its likely deterioration with time. It is thus a very useful tool in the hands of a maintenance engineer. It is good practice to take roughness measurements on the entire network of concrete roads in the country, at least once every three years and to maintain the permanent record of the same.

4.3.3 Moving profilographs or laser device are often used to measure the depth of irregularities in the road surface. Standards related to profile measurement and data analysis have been developed by ASTM under ASTM E 950 and ASTM E 1364. The indigenous response type fifth wheel bump integrator (BI) which measures suspension deflections (originally developed by TRRL in the UK) towed over the road surface (preferably in the wheel path) at a steady speed of 32+/-1 km/hour has to date been generally used in the country to evaluate the roughness in terms of mm/km. A brief description of the above equipment and procedures for calibration are given in the IRC publication "Guidelines for Surface Evenness of Highway Pavements", IRC:SP:16.

4.3.4 The roughness of a pavement is commonly reported in terms of an unevenness index as measured by the bump integrator. The maximum permissible roughness values (expressed in "mm/km") recommended by IRC:SP:16 for the roads with different types of surfaces are given in **Table 4.2**

Table 4.2 Recommended Roughness Values for Roads in India*
(Ref: 1.11- Table 3, IRC:SP:16)

Wearing Surface Type	Condition of Road Surface					
	Good		Average		Poor	
	BI mm/km	IRI m/km	BI mm/km	IRI m/km	BI mm/km	IRI m/km
Bituminous Concrete (BC)	< 2000	2.8	2000-3000	2.8-4.0	> 3000	> 4.0
Cement Concrete (CC)	< 2200	3.0	2200-3000	3.0-4.0	> 3000	> 4.0

* It is possible and desirable to construct roads with roughness level lower than above with the use of modern equipment and construction practices supported with adequate logistics commensurate with the capacity of paver etc.

4.3.5 Two methods of reporting the roughness are commonly followed. One is based on the bump integrator (BI) in mm/km as described above and the other is based on the International Roughness Index (IRI) in m/km. **Table 4.3** gives the conversion values between BI and IRI.

Table 4.3 Conversion BI mm/km to IRI m/km Recommended Roughness Values for Roads
(IRC:SP:16)

IRI (m/km)	1.0	1.2	1.4	2.0	2.5	3.0	4.0
BI (mm/km)	630	770	920	1370	1760	2160	3000

Note: BI in mm/km = 630 x (IRI in m/km)^{1.12}

4.4 Structural Evaluation

4.4.1 The structural performance of the pavement refers to its ability to carry future traffic.

4.4.2 There are a number of means of assessing structural capacity by measuring deflection and curvature of the pavement under heavy axle load.

4.4.3 Deflection based non destructive testing methods such as Falling Weight Deflectometer (FWD) are generally preferred as destructive testing is cumbersome, time consuming and costly.

4.4.4 There are cases when pavement in long continuous stretch is badly damaged or distressed. In all such cases, it may be considered desirable that pavement in such condition be opened up and each layer is tested to identify the exact cause of failure/distress. The FWD is a very quick and accurate method for assessing residual life of the pavement, and also for overlay design. The FWD is attached to a 4 wheeled vehicle, and results recorded directly on to computer disc, for later analyses.

4.5 Measurement and Degree of Severity of Defects

4.5.1 The severity of any type of distress can be evaluated by the measurement of one or two parameters that best characterise that type of distress.

- a) Deformation in the pavement may be due to faulting, drop-off shoulder, heaving, blow up etc. Deformation is measured in terms of level difference in mm by using a straight edge and a graduated wedge or tape.
- b) Individual cracks can be evaluated by measuring their width in mm. This can be done by inserting metal strips of standard gauge thickness or by optical microscope (**Fig. 4.1**). Measurement of crack length and its variation with time is also important. Cracks that run across one or more slabs are particularly severe and result from concrete tensile failure. The maximum crack width shall be recorded as representative of at least 50% of its length.
- c) Multiple and hair cracks can be evaluated by measuring the total length of cracks in mm/m² within a square frame with 1 m long sides.
- d) For cracks, it is also very important to know their depth, because full depth cracks ($>D/2$) allow ingress of water and undermine the strength of the slab and the pavement. On the other hand some kinds of shallow cracks, such as shrinkage cracks do not need to be repaired if they are isolated and short. The crack depth can be determined in cores bored from the pavement or by ultrasonic pulse velocity measurements across the crack. The depth as determined by this method is about 60 to 70 % of the actual depth as determined by the former method.
- e) Surface loss (ravelling and scaling) can be evaluated by its percentage of damaged area and its maximum depth.
- f) Joint spalling can be evaluated by measuring its width in mm. Refer **Figs 4.2 (a) & (b)**. The maximum spalling width shall be recorded
- g) Individual popouts and potholes can be evaluated by measuring their diameters and depths. Multiple popouts can be evaluated by their number per square metre.

- h) Surface wearing can be evaluated by its area density as a percentage and the textural depth (sand patch test) or skid resistance of the worn surface.
- i) Patching can be evaluated as the percentage area patched to the total area of the slab.



Fig. 4.1 Optical Microscope for Measuring Crack Width

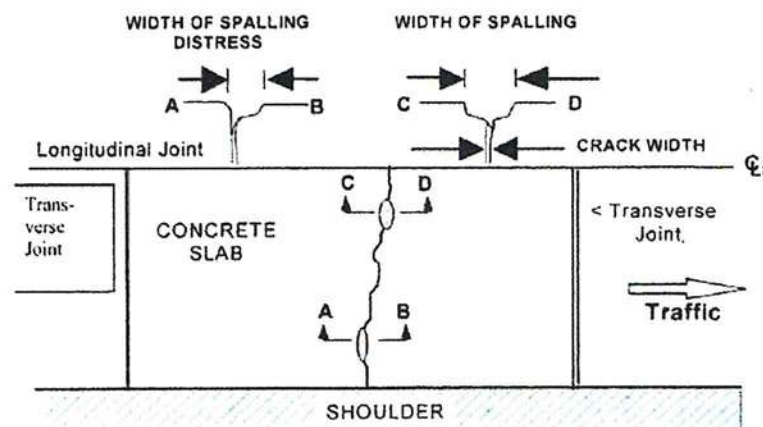


Fig. 4.2 (a) Measurement of Spalling at a Crack

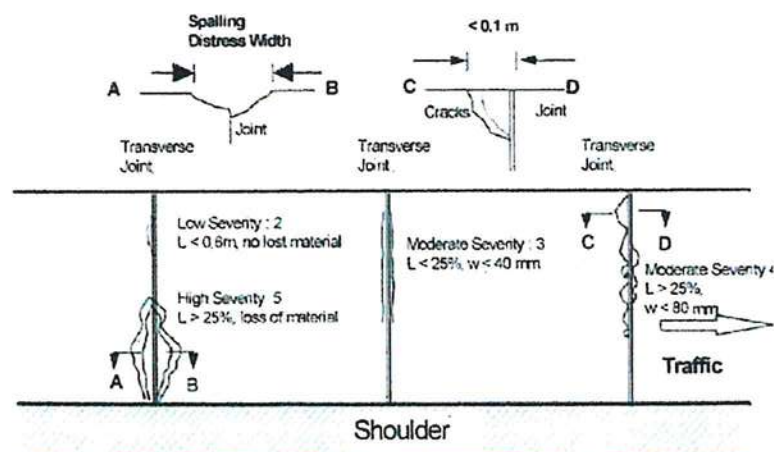


Fig. 4.2 (b) Measurement of Spalling at a Joint

4.6 Distress Rating System

4.6.1 The routine survey and recording of the surface condition and rating of severity of defects is important for assessing the maintenance strategy. The airports authorities use such a system and several roads authorities around the world use similar ratings systems. Some define three degrees of severity (low, medium and high), some five degrees and others ten degrees. A 5-level distress rating system is recommended in these guidelines. This is given in **Table 4.4**.

Table 4.4 Five Level Distress Rating System

Distress Rating	Slab Condition	Severity(Defects) Rating
0	Excellent	Not Discernible
1	Very Good	Minor
2	Good/Average	Moderate
3	Fair	Major
4	Poor	Extreme
5	Very Poor	Unsafe/Unserviceable

4.6.2 Type of repair can be appropriately decided from the distress rating as per details of **Table 4.5**. The techniques for repair can be selected from **Table 5.1** and **5.2**. The guidance as to the materials suitable for repair is given in Chapter 12. The materials selected should provide the desired performance and durability of 6 to 8 years minimum. Concrete mix proportion characteristics are given in **Appendix B** for early opening to traffic (EOT) in case of emergency repairs.

4.6.3 The severity level of the defects and distress develop during the contract defect liability period (usually specified as the first year after substantial completion) should generally not exceed degree 2. More time is necessary for distress development under traffic loading, climatic influences and/or unattended maintenance to reach degrees of severity 3 and 4. If degree of severity level 3 was exceeded during the defect liability period of the construction contract, this would probably have to be explained by relevant design and construction shortcomings and rectified under the terms of the contract. These days the Employer specifies 4 yrs defect liability period and it is the responsibility of Contractor to repair all distresses above severity level 2 in **Table 4.4**.

4.6.4 Distresses with degree of severity of 5 (like wide cracks with spalling and/or scaling) exceeding 50% area and/or faulting exceeding 12 mm or broken slabs exhibiting rocking effect may be considered for slab replacement.

4.7 Monitoring Performance

Performance or serviceability of the new roads or the roads after repair shall be assessed as per Para 4.2.

Table 4.5 Repair Actions for Different Degrees of Severity of Distress* in Concrete Pavements

*According to the 5 level severity rating system : 0 - Not Discernible, 1 - Minor, 2 - Moderate, 3 - Major, 4 - Extreme and 5 - Unsafe/Unserviceable

S.No.	Type of Distress	Degree of Severity	Assessment Rating	Repair Action	
				For the case $d < D/2$	For the case $d > D/2$
1	CRACKING Single Discrete Cracks Not intersecting with any joint	0	Nil, not discernible	No Action	
		1	$w < 0.2$ mm, hair cracks		
		2	$w = 0.2 - 0.5$ mm, discernible from slow-moving car	Seal without delay	Full Depth Repair
		3	$w = 0.5 - 1.5$ mm, discernible from fast-moving car		Dismantle and reconstruct affected portion - See Para 5.4
		4	$w = 1.5 - 3.0$ mm	Seal, and stitch if $L > 1$ m.	
		5	$w > 3$ mm.		
2	Single Transverse (or Diag) intersecting with one or more joints	0	Nil, not discernible	No Action	
		1	$w < 0.2$ mm, hair cracks	Route and Seal	Seal and Cross-stitch or staple
		2	$w = 0.2 - 0.5$ mm, discernible from slow vehicle		
		3	$w = 0.5 - 3.0$ mm, discernible from fast vehicle	Seal, and stitch if $L > 1$ m.	Full Depth Repair Dismantle and reconstruct affected portion - See Fig 5.5 and Refer Chapter 9
		4	$w = 3.0 - 6.0$ mm	Not applicable	Staple or Dowel Bar Retrofit
		5	$w > 6$ mm, usually associated with spalling, and/or slab rocking under traffic	Not applicable (Full Depth Crack)	Staple or Dowel Bar Retrofit
3	Single Longitudinal Crack intersecting with one or more joints	0	Nil, not discernible	No Action	
		1	$w < 0.5$ mm, discernible from slow moving vehicle	Seal, and stitch if $L > 1$ m.	Seal and Cross-stitch or staple
		2	$w = 0.5 - 3.0$ mm, discernible from fast vehicle		
		3	$w = 3.0 - 6.0$ mm	Seal and Staple	Partial Depth Repair with or without dowel bar retrofit, or
		4	$w = 6.0 - 12.0$ mm	Not applicable	Full Depth Repair
		5	$w > 12$ mm, usually associated with spalling, and/or slab rocking under traffic	Not applicable (Rocking/Spalling indicates Full Depth Crack)	Dismantle and reconstruct affected portion - See Fig 5.6 and Chapter 9
4	Multiple Cracks intersecting with one or more joints or cracks	0	Nil, not discernible	No Action	
		1	$w < 0.2$ mm, hair cracks	Seal, and stitch if $L > 1$ m.	
		2	$w = 0.2 - 0.5$ mm, discernible from slow vehicle		Dismantle and reconstruct whole slab
		3	$w = 0.5 - 3.0$ mm, discernible from fast vehicle	Full depth repair	
		4	$w = 3.0 - 6.0$ mm panel broken into 2 or 3 pieces		Reinstate subbase, Reconstruct whole slab.
		5	$w > 6$ mm and/or panel broken into more than 4 pieces		
5	Corner Break	0	Nil, not discernible	For the case $d < D/2$ No Action	For the case $d > D/2$
		1	$w < 0.5$ mm; only 1 corner broken	Seal with low viscosity epoxy to secure broken parts	
		2	$w < 1.5$ mm; $L < 0.6$ m, only one corner broken		
		3	$w < 1.5$ mm; $L < 0.6$ m, two corners broken	Partial Depth Repair - See Fig. 8.3	Full depth repair
		4	$w > 1.5$ mm; $L > 0.6$ m or three corners broken		Reinstate subbase.
		5	three or four corners broken		
6	Punchout (Applicable to CRCP only)	0	Nil, not discernible	No action.	
		1	$w < 0.5$ mm; $L < 3$ m / m ²		Seal with low viscosity epoxy to secure broken parts
		2	either $w > 0.5$ mm or $L < 3$ m / m ²	Not applicable (Punchout is Full Depth Distress)	
		3	$w > 1.5$ mm and $L < 3$ m / m ²		Full depth repair - Cut out and replace damaged area taking care not to damage reinforcement
		4	$w > 3$ mm, $L < 3$ m / m ² and deformation		
		5	$w > 3$ mm, $L > 3$ m / m ² and deformation		

7	Ravelling or Honeycomb type surface	0	Nil, not discernible	No action.	Not Applicable
		1	$r < 2\%$	Local repair of areas damaged and liable to damage.	
		2	$r = 2 - 10\%$	Bonded Inlay if affecting 2 or 3 slabs	
		3	$r = 10 - 25\%$		
		4	$r = 25 - 50\%$		
		5	$r > 50\%$ and $h > 25$ mm	Reconstruct slabs if affecting 4 or more slabs	
8	Scaling	0	Nil, not discernible	No action.	Not Applicable
		1	$r < 2\%$	Local repair of areas damaged and liable to damage	
		2	$r = 2 - 10\%$		
		3	$r = 10 - 20\%$	Bonded Inlay	
		4	$r = 20 - 30\%$		
		5	$r > 30\%$ and $h > 25$ mm	Reconstruct slab	
9	Polished Surface / Glazing	0		No action.	Not Applicable
		1	$t > 1$ mm		
		2	$t = 1 - 0.6$ mm	Monitor rate of deterioration	
		3	$t = 0.6 - 0.3$ mm		
		4			
		5	$t < 0.3$ mm	diamond Grinding if affecting 50% or more slabs in a continuous stretch of minimum 5 km	
10	Popout (Small Hole). Pothole	0	$d < 50$ mm; $h < 25$ mm; $n < 1$ per 5 m ²	No action.	Not Applicable
		1	$d = 50 - 100$ mm; $h < 50$ mm; $n < 1$ per 5 m ²	Partial depth repair 65 mm deep	
		2	$d = 50 - 100$ mm; $h > 50$ mm; $n < 1$ per 5 m ²		
		3	$d = 100 - 300$ mm; $h < 100$ mm; $n < 1$ per 5 m ²	Partial depth repair 110 mm i.e 10 mm more than the depth of the hole	
		4	$d = 100 - 300$ mm; $h > 100$ mm; $n < 1$ per 5 m ²		
		5	$d > 300$ mm; $h > 100$ mm; $n > 1$ per 5 m ²	Full depth repair	
11	JOINT DEFECTS Joint Seal Defects	0	Difficult to discern.	SHORT TERM No action.	LONG TERM Not Applicable
		1	Discernible, $L < 25\%$ but of little immediate consequence with regard to ingress of water or trapping incompressible material.	Clean joint, inspect later.	
		3	Notable, $L > 25\%$ insufficient protection against ingress of water and trapping incompressible material.	Clean and reapply sealant in selected locations	
		5	Severe: $w > 3$ mm negligible protection against ingress of water and trapping incompressible material.	Clean, widen and reseal the joint following strict procedures.	
12	Spalling of Joints	0	Nil, not discernible	No action.	Not Applicable
		1	$w < 10$ mm	Apply low viscosity epoxy resin / mortar in cracked	
		2	$w = 10 - 20$ mm, $L < 25\%$	do	
		3	$w = 20 - 40$ mm $L > 25\%$	Partial Depth Repair 30 - 50 mm deep, $h = w + 20\%$ of w	
		4	$w = 40 - 80$ mm $L > 25\%$		
		5	$w > 80$ mm, and $L > 25\%$	50 - 100 mm deep repair. $H = w + 20\%$ of w	

13	Faulting (or Stepping) in Cracks or Joints	0	not discernible, < 1 mm	No action.	Not Applicable
		1	f < 3 mm	Determine cause	
		2	f = 3 - 6 mm	Diamond Grinding	
		3	f = 6 - 12 mm	Raise sunken slab.	
		4	f = 12 - 18 mm	Strengthen subgrade and subbase by grouting.	
		5	f > 18 mm		
14	Blowup or Buckling	0	Nil, not discernible	No action.	Not Applicable
		1	h < 6 mm		
		2	h = 6 - 12 mm	Install Signs to Warn Traffic	
		3	h = 12 - 25 mm	Full Depth Repair	
		4	h > 25 mm	Replace broken slabs.	
		5	shattered slabs, ie 4 or more pieces		
15	Depression	0	Not discernable, h < 5 mm	No action.	Not Applicable
		1	h = 5 - 15 mm		
		2	h = 15 - 30 mm, Nos < 20% joints	Install Signs to Warn Traffic	
		3	h = 30 - 50 mm		
		4	h > 50 mm or > 20% joints	Strengthen subgrade.	
		5	h > 100 mm	Reinstate pavement at normal	
				SHORT TERM	LONG TERM
16	Heave	0	Not discernable, h < 5 mm	No action.	scquabble
		1	h = 5 - 15 mm	Follow up.	
		2	h = 15 - 30 mm, Nos < 20% joints	Install Signs to Warn Traffic	
		3	h = 30 - 50 mm	Stabilise subgrade.	
		4	h > 50 mm or > 20% joints	Reinstate pavement at normal	
		5	h > 100 mm		
17	Bump	0	h < 4 mm	No action.	Construction Limit for New Construction
		1	h = 4 - 7 mm	Grind, in case of new construction	
		3	h = 7 - 15 mm	Grind in case of ongoing maintenance	
		5	h > 15 mm		
18	Lane to Shoulder Dropoff	0	Nil, not discernible < 3mm	No action.	For any 100 m segment Reconstruct shoulder. if affecting 25% or more of segment
		1	f = 3 - 10 mm	Spot repair of shoulder.	
		2	f = 10 - 25 mm		
		3	f = 25 - 50 mm	Fill up shoulder	
		4	f = 50 - 75 mm		
		5	f > 75 mm		
DRAINAGE					
19	Pumping	0	not discernible	No Action	Inspect and repair subdrainage at distressed sections and upstream.
		1 to 2	slight/ occasional Nos < 10%	Repair cracks and joints without delay.	
		3 to 4	appreciable / Frequent 10 - 25%	Lift or jack slab.	
		5	abundant, crack development > 25%	Repair distressed pavement sections. Strengthen subgrade and subbase. Replace slab.	
20	Ponding	0-2	No discernable problem	No action.	Action required to stop water damaging foundation
		3 to 4	Blockges observed in drains, but water flowing	Clean drains etc, Follow up,deep grooving in transvers direction to remove water	
		5	Ponding, acculation of water observed	deep grooving in transvers direction to remove water-hydro planning	

Adapted from Ref: 3.3 - Committee of State Road Authorities, Pretoria, South Africa, 1990, Standard Nomenclature and Methods for Describing the Condition of Jointed Concrete Pavements, Technical Recommendations for Highways, Draft TRH19:1989, p. 1 – 49. in consultation with CRRI, January 2006.

PROFORMA 4.1

		Contract No.		(Project Description) (From Km to Km)	
TAKING OVER RIGID PAVEMENT INSPECTION DETAILS (GC. 48)					
Section 1 / Part - Sample for guidance from an executed project road					
				Left / Right Side (strike out)	
Defects Observed During Joint Inspection Conducted on: _____					
by: _____					
To _____ ↑					
Field Notes:	H/Shoulder	Left Lane	Right Lane		
surface shrinkage cracks, (1mm/SR 2) seal with low viscosity epoxy resin	Joint	}	}	Median Kerb	96+776.5
		}	}		96+772
spalling in wheel path	Joint				96+795
shallow shrinkage crack 1mm	Joint	20cm }			96+835
		40cm			
sealant lost/missing	Joint				97+158
seal shrinkage cracks (1mm/SR 2) with low viscosity epoxy resin		surface crazing }	shrinkage crack }		97+285
seal with low viscosity epoxy resin	Joint	40c m }			
		20c m }	90 cm }	40cm	97+456
Other Comments:					
1. All kerbs and hard shoulder to be cleaned of debris, stones etc 2. Centre line marking for defective, breaking up		Signed by: _____		Accepted by: _____	
		For the Engineer		For the Contractor	
Date: _____		Date: _____			

PROFORMA 4.2 LOCATION AND CONDITION OF FULL DEPTH CRACKS & OTHER SERIOUS DEFECTS IN PQC SLABS (Note: This list excludes Fine Cracks and Shallow Plastic Shrinkage Cracking)

Sr. No.	Location		Date Cast	Type of Defect	Seventy Rating	Proposed Treatment	No. Slabs Affected	First Reported		Latest Condition Reported			Photo Record Neg. No.	Reasons Given for Defect	Status of Rectification as on date 30.01.06
	New km from	Old Ch from						Date	Crack Width (mm)	Date	Crack Width (mm)	Spalling (mm)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Sample for Guidance: Left Hand Carriageway															
1	85.830		08.10.02	Longitudinal Crack (New)	1	Stitch and Seal, Saw/Chip 10 mm Wide up 25 mm deep and seal	5	06/09/05		06/09/05	0.2-0.3	<5 mm		Consolidation under Parked Trucks	Rectified on 07.06.06
2	96.709		03.03.03	Transverse Crack Near Joint	3	Dismantle and reconstruct whole slab,	3	14.09.04		06/09/05	1-2	<40 mm		Shrinkage	Rectified on 07.01.06
3	102.399			Multiple Cracks at Local Depression	3	Partial depth Repair with High Performance Mortar/Concrete	1	20/09/04		01/07/05	<0.5 mm	Depression >12 mm		Trafficed during curing Period	Rectified on 17.07.06
4	104.102		24.04.03	Transverse Crack Near Joint	4	Cut out Full Depth and Replace Affected Portion 2.1 m	3	20/09/04		01/07/05	3	<20 mm		Trafficed during curing Period	Rectified on 08.10.06
5	104.362		26.04.03	Transverse Crack Near Joint	3	Cut out Full Depth and Replace Affected Portion 1.8 m	3	20/09/04		01/07/05	3	<20 mm		Shrinkage	Rectified on 28.09.06
6	106.312		14.05.03	Diagonal Crack	4	Dismantle and reconstruct whole slab,	3	21/09/04		01/07/05	0.5	<40 mm		Shrinkage	Rectified on 30.10.06
7	107.802		20.05.03	Transverse Crack	4	Dismantle and reconstruct whole slab,	3	21/09/04		29/06/05	0.5	<10 mm		Shrinkage	Replaced whole slab on 05.12.06
8	107.117		21.05.03	Multiple Cracks	5	Dismantle and reconstruct whole slab,	2	21/09/04		29/06/05	1	<80 mm		Trafficed during curing Period	Replaced whole slab on 17.12.06
9	107.233		21.05.03	Multiple Cracks at Local Depression	3	Partial depth Repair with High Performance Mortar/Concrete	4	21/09/04		29/06/05	0.5	<40 mm		Trafficed during curing Period	Rectified on 17.10.06

No Transverse Crack	=	8
No. Longitudinal	=	3
No. Multiple/Other	=	3
No. Serious Surface Defects	=	2
Total		16

37

PROFORMA 4.3

RIGID PAVEMENT CONDITION SURVEY AND DISTRESS RATING		Page: _____ of _____ Date: _____ Sign.: _____
ROAD: _____ SECTION: _____		
LINEAR SKETCH		LHS to RHS to (Strike out which is not applicable)
CHAINAGE (km)		
ALIGN- MENT	LAYOUT <small>(LONG. ALIGN., gradient, %)</small>	
CROSS SECTION <small>height (m), Crossfall (%)</small>		
FAULTING / STEPPING		
BUMP		
BLOWUP / BULKING, SHATTERING		
TRANSVERSE CRACK		
DIAGONAL CRACK		
LONGITUDINAL CRACK		
CORNER BREAK		
MULTIPLE CRACKS		
RAVELLING, SCALING		
POPOUT, POTHOLE		
JOINT SPALLING		
JOINT DAMAGE		
LOSS OF SURFACE TEXTURE		
SLAB / EDGE PUNCHOUT		
PUMPING		
Rigid Shoulder (Y/N)		
Soft Shoulder (Y/N)		
Side Ditch (Y/N)		
DRAINAGE		
CONDITION Good, Poor		

PROFORMA 4.4

Contract No: _____
 (Name of Contract)
 (Limits of Contract)

DRAINAGE CONDITION SURVEY DATA

Section/Part – Main Carriageway
 Left/Right Side (strike out)

Joint Inspection Conducted on : _____
 By : _____
 Designation : _____

SITE INFORMATION :**1. Side Drainage (visual)**

Depth to roadside ditch (mm) :	
Condition of roadside ditch satisfactory/poor :	
Type of drainage system present :	
0 = none; 1 = open kuchcha drain; 2 = open pakka drain; 3 = covered drain	
Distance to discharge point (m)	
Remarks:	

2. Sealant/Lane/Shoulder Joint Integrity (Severity Rating : Reference Table 4.5 : Para)

Sealant Type (Circle)	None - HP - PS - SI - UR - Preformed - Other	
HP = Hot poured ; PS = Polysulphide ; SI = Silicone ; UR = Urethane		
	Paved shoulders (Circle)	Traffic lanes (Circle)
Sealant condition (SR)	0 - 1 - 2 - 3 - 4 - 5	0 - 1 - 2 - 3 - 4 - 5
Shoulder condition (SR)	0 - 1 - 2 - 3 - 4 - 5	0 - 1 - 2 - 3 - 4 - 5
SR = Severity rating (see Table 4.4)		

3. **Condition of Vegetation on Embankment** Cut Not Cut

4. SUMMARY – Overall Assessment of the quality of Drainage

Poor drainage	
Fair drainage	
Good drainage	
Very good drainage	

5. OTHER OBSERVATION REMARKS (with sketches, if required) :

(Adopted from Protocol TP-16, Repair and Rehabilitation of Concrete pavements
 Part II Guidelines for Condition Assessment and Evaluation, Report No: FWHA-01-C-000802004, 2004)

5 METHODS FOR REPAIRING CONCRETE PAVEMENTS

5.1 Types of Repair Techniques

Repair techniques can be broadly classified into two categories:

- i. Preventive Techniques
- ii. Corrective Techniques

Preventive techniques are pro-active techniques/activities. These are aimed to slow down or prevent the occurrence of the distress so as to ensure a longer service life of the pavement. Joint and crack resealing are the most commonly applied preventive repair techniques. Full depth repairs are examples of corrective repair activities. There are a number of corrective activities/repair techniques which perform both the function of corrective as well as preventive repair activities. Diamond grinding, grooving, slab stabilization, cross-stitching, retrofitting of dowel bars/edge drains and retexturing are some of the activities of the repair techniques which act both as corrective and preventive repair activities.

5.2 Concrete Pavement Restoration Techniques

5.2.1 Concrete Pavement in real situations suffers from one distress or, many times, with a combination of distresses. There are different techniques to tackle individual distresses. More often, a combination of repair techniques is required to be applied as illustrated in **Fig. 5.1**. Preventive techniques in many situations may help the pavement to perform for many years but may not provide a very long-term solution.

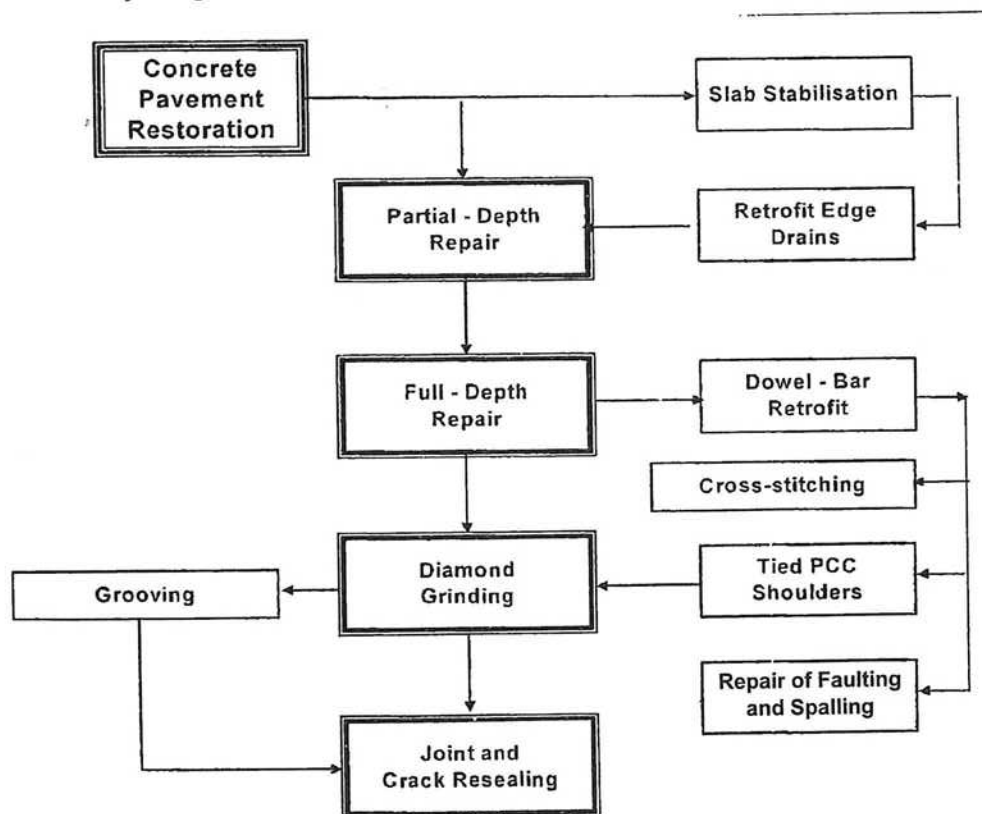


Fig. 5.1 Sequence of Concrete Pavement Restoration Techniques (CPR)

5.2.2 Budgetary resources will sometime dictate whether we should go for preventive repair activities to be followed by corrective repair activities or directly to corrective repair activities. The latter option will also be dictated by the degree of the severity of distress and urgency of repair. For example, in case of full depth/deep transverse cracks, resealing can be done early, so that further ingress of water into the pavement is prevented. It can run for some years. Later on to restore the structural integrity of pavement, appropriate corrective repair activities like dowel bar retrofit or full depth repair may be undertaken.

5.2.3 Different activities have to follow a defined sequence. Full depth repairs, dowel bar retrofit or cross-stitching activities must precede the diamond grinding, grooving and resealing of joints. ACPA has suggested a model sequencing pattern which may be considered as a guide in this respect. This sequence is given in **Fig. 5.1**. All locations may not require every repair technique procedure or a combination of procedures. Individual technique/procedure may suffice in many cases.

5.2.4 The selection and application of a particular repair technique at the proper time is essential for good performance of the concrete pavement. The actual selection of the particular repair technique shall depend on the following:

1. Type and extent of severity level of distress/damage
2. Causes of distresses are as given in **Table 3.1**
3. Bearing capacity of subbase and subgrade. Where insufficient bearing capacity is the cause of the distress the subgrade and/or subbase should also be strengthened and/or stabilized
4. Volume of traffic and traffic diversion conditions during the work, repair methods that require short work and curing times shall be preferred
5. Possible reuse of salvaged materials such as recycling of demolished concrete in DLC
6. Responsibility for payment, i.e. repair obligation of the construction agency under defect liability provisions of the contract or payment by the operating agency after defect liability period or handing over whichever is later.

5.3 Timing of Distress Repair

5.3.1 New construction

5.3.1.1 The acceptance criteria for new construction shall be governed by IRC:15 "Code of Practice for Construction of Jointed Plain Concrete Pavements". The acceptance criteria prescribed for cracked concrete slabs is in line with the MoRT&H Specification Clause 602.9.9.4 which states that "The Contractor shall be liable at his expense to replace any concrete damaged as a result of incomplete curing or cracked on a line other than that of a joint". As already stated before, the repair of new concrete pavement, within the defect liability period shall be governed by the relevant Clauses of the contract. In case where the contract clauses do not provide any specific acceptance criteria for new construction then for such cases it is recommended that acceptance criteria should be that all distresses of low severity (2 or less) vide **Tables 4.4** and **4.5** shall be accepted with minor repair as per the

discretion of the Engineer-in-Charge. In case severity is of 4 and 5, it should not be accepted. For severity 3, the client may apply its discretion depending upon the nature/type of distress and considering that certain types of repairs like partial depth repairs etc. are likely to last 6-8 years only.

5.3.2 *Old construction (after defect liability period)*

5.3.2.1 For concrete roads in operation, the cost of repair and lane closure are two important considerations in deciding the type of repair to be undertaken. Pavements have their defined service life. Repairs are intended only to ensure that concrete pavements perform till designed service life. The strategies for repair of older pavements could be thus different than those of new pavements. Decision is based on a tradeoff between the "cost" of repair and the "remaining" life of the pavement. Road Authorities may decide suitably.

5.3.2.2 Alternative repair strategies for existing pavements are given in the last two columns of **Table 4.5**. The type of repair to be undertaken, primarily depends upon whether distress is of a structural nature or of non-structural nature. For these guidelines all cracks/distresses are non-structural in nature, when " $d < D/2$ ", where " d " is the depth of crack or distress and " D " is the thickness of the slab (PQC). Preventive repair activity in cases, where $d < D/2$ are recommended. When " $d > D/2$ " i.e. depth of crack/distress is more than half the thickness of the slab, such cracks/distresses are structural in nature. The repair methods recommended are corrective in nature where $d > D/2$. As stated before, the repair and maintenance strategies to be followed may involve either short term measure or long term measure or a combination of both with time spacing to suit the specific condition of distress, availability of fund etc. For repairs where " $d > D/2$ ", the procedure given in para 5.4.5 or 5.4.6 or 5.4.7 as per site specific distress may be followed.

5.4 Distress to be Repaired

5.4.1 Visible distressed areas should be repaired according to the standards specified in the contract (if applicable) or as per the **Tables 4.4** and **4.5** whichever sets the more stringent condition.

5.4.2 Generally distress types of low severity (2 or less) may be left with minor repair. Structural distress with severity 4 and 5 as per **Table 4.5** shall receive priority repair, to minimize further damage to the pavement structure with time, to avoid costly repairs/reconstruction. In such cases, short term repairs may precede the long term repair as per **Table 4.5** to avoid damage extension due to delay in long term repair.

5.4.3 Some types of distress like depressions, heave, single crack, raveling, loss of surface texture will only need repair for degrees of severity of 3 or more. Working cracks will be treated with dowel retrofit or with full depth repair depending on degree of severity. Full depth repair are to be undertaken in case of extreme severity.

5.4.4 Single, shallow fine/hair cracks do not require repair. Fine plastic shrinkage cracks are believed to be self healing (autogenous). Fine interconnecting cracks (crazing) should be considered as surface distress and repaired with low viscosity epoxy resins as shown in **Figs. 5.2** and **5.3** before propagating further and developing ravelling.

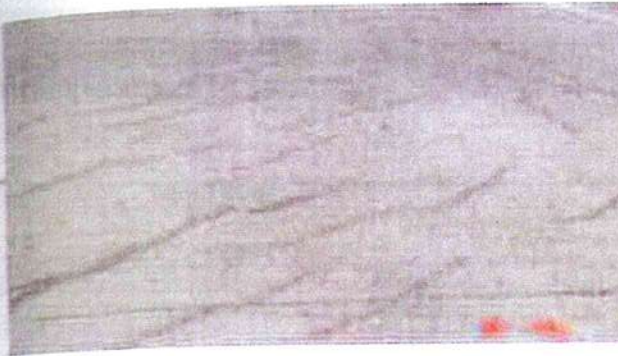


Fig. 5.2 Plastic Shrinkage Cracks Repaired with Low Viscosity Epoxy



Fig. 5.3 Close Up View of Epoxy Sealing

5.4.5 Full depth cracks and damaged joints shall be sealed without delay to minimise ingress of water/incompressibles into the pavement structure. This should be followed with dowel retrofit or full depth repair.

5.4.6 Full depth repair is recommended, if weak concrete is identified or suspected or the pavement had multiple type of distresses such as cracking, ravelling, large pop-outs/potholes and compression failure as blowups etc. Slab areas surrounding the visible distressed area should be sound when struck by a hammer and all areas sounding dull/hollow shall be included in the repair/boundaries. Weak concrete may extend to neighbouring slabs, and such slabs should also be repaired.

5.4.7 Repair priority should be given to full depth cracks across one or more slabs. The repair of this type of structural distress developing after trafficking for some period often requires sub-grade stabilisation. Repair of full depth transverse cracks always requires new dowel bars to be placed and one new joint constructed as shown in **Fig. 5.4**. The large cracked slab is thus replaced by two smaller slabs with lower curl and warping stresses.



(a) Full Depth Repair with drilled-in Dowel Bars (with two new construction joints)



(b) Full Depth Repair with Grouted Tie Bar & Dowel Bars Assembly (Contraction Joint)

Fig. 5.4 Full Depth Repair

5.4.8 The purpose of joint sealants is to prevent ingress of water and incompressible foreign materials. The condition of joint sealant should be watched at regular interval, particularly, before the on-set of monsoon. This should be replaced, when it is worn out, lost adhesion from the groove walls of the joints, hardened badly (oxidized) and has become brittle, has oozed out completely.

5.5 Repair Methodology

5.5.1 Tables 5.1 and 5.2 list a range of techniques and applications for repairing and restoring the integrity of the concrete pavement slab.

Table 5.1 Concrete Pavement Repair Techniques (Preventive Activities)*

(Ref: ACPA Concrete Pavement Restoration Guide)

S.No.	Repair Technique	Application
1	Crack and Joint resealing with flexible sealant	Used to minimize infiltration of water and incompressible material into joint system
2	Crack sealing with epoxy resin	Used to seal shallow fine to medium width cracks and prevent concrete breaking out at spalls.
3	Crack cross stitching	Used to repair low and medium severity longitudinal cracks.
4	Partial depth repairs	Used to repair joint and crack deterioration and surface distress. Used to repair popouts and potholes.

Table 5.2 Concrete Pavement Repair Techniques (Corrective Activities)*

(Ref: ACPA Concrete Pavement Restoration Guide)

S.No.	Repair Technique	Application
1	Full depth repairs	Used to repair full depth cracks and joint deterioration. Used to repair punchouts (CRCP)
2	Slab stabilization	A specialized technique used to alleviate pumping
3	Dowel bar retrofit	A specialized technique used to restore load transfer at joints and cracks
4	Slab lifting or jacking	A specialized technique used to raise sunken slabs by lifting or pressure grouting beneath the panel.
5	Diamond grinding	A specialized technique used to extend serviceability, improve ride and skid resistance
6	Diamond Grooving	A specialized technique used to reduce wet weather accidents and prevent hydroplaning

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5.6 Prerequisite Activities for All Types of Repairs

5.6.1 General

All repair techniques discussed in the guidelines will start with the following preparatory activities-

1. Marking out the areas to be repaired.
2. Making the temporary working area safe for the workmen from the passing traffic by temporary barricading, signage etc.
3. Dismantling the affected areas and disposing of the broken concrete in an appropriate way.
4. Any other activities as per the direction of the Engineer in Charge.

5.6.2 *Marking areas to be repaired*

The following activities shall be undertaken for appropriately marking out the area to be repaired.

- a) The total distressed and surrounding areas (to be repaired) are marked on the pavement in rectangular form with sides parallel and perpendicular to the centre line after sounding with a hand hammer, ensuring not less than 50 mm cutting beyond unsound concrete. Rectangular areas simplify saw cutting and concrete removal.
- b) All full depth repairs shall be made to the full width of a lane to achieve stable patches and provide adequate room in the pit for dowel hole drill rigs and compaction equipment.
- c) The area to be repaired for a full depth transverse crack shall be a transverse strip. The width will depend on the crack alignment. Odd shaped slabs ($L/B > 1.5$) and mismatched slabs shall be reinforced with 10 mm dia bars placed at depth of 75 mm from the top and 200 mm C/C both ways.
- d) If the transverse crack is close to a joint (< 1500 mm from the joint) one of the sides of the area to be repaired shall be the nearest joint itself.
- e) The newly cut joint faces shall be scabbled with a chisel or sand blasted to create roughness for better bond between old and new concrete.
- f) Partial depth repairs are usually smaller than 1m in length. For partial depth repairs if the distance between patches is smaller than 300 mm, the patches are combined in a single large patch.
- g) When two different areas to be repaired or patches are close to each other the repair may be faster and cheaper if the adjacent areas are combined in a large patch.
- h) The criteria for combining adjacent full-depth patches depend on slab thickness and the patch in case of (partial width repair) or lane in case of (full-width repair) width.

5.6.3 *Layout for repair of wide full width cracks ($d > D/2$)/full depth repair (FDR):*

The following activities shall be undertaken:

- a) The layout recommended for repair of full width transverse cracks depends on the location of the crack with respect to the joints and free edges as shown in **Fig. 5.5.**

- b) Transverse cracks extending full width of the panel or continuous longitudinal cracks intersecting with formed or sawn joints are not acceptable in new construction i.e. before "Taking Over" from the contractor by the client as per IRC:15 and MoRT&H Specifications for Road and Bridge Works. However, these may be provided with tie or dowel bars as part of a short term maintenance strategy after "Taking Over". Dowel bars shall be used in such conditions where widening of the crack may occur.
- c) For cracks at a distance of more than 1.5 m from the next transverse joint, slots for retrofitting of dowel bars shall be cut and the dowel bars placed at distances of 250- 300 mm before the crack is widened and sealed. This is a stop gap arrangement. The permanent treatment would be to make a full slab replacement or cutting out the affected part of slab by full depth cutting. Holes are drilled for tie bars and additional contraction joint is made by providing dowel bars (See **Fig. 5.5**).
- d) For cracks located at short distances from joints (ie. at less than 1.5 m) the strip of slab between the crack and the joint shall be cut to a regular rectangular shape and removed. The condition of the existing dowel bars shall be checked and new holes for new tie bars shall be drilled in the opposite sawn cut face. These shall be thoroughly cleaned with compressed jet air and filled with a thick epoxy. The tie bar shall be inserted by hammer imparting light thuds at the head of the tie bar so that the epoxy oozes out insuring complete bond between the circular wall of the whole and ribbed surface of the tie bars. The epoxy shall be allowed to cure for a minimum period of four hour.
- e) If the slab displays more than two full width cracks complete slab reconstruction shall be considered or repair may be carried out as per the advice of Engineer.
- f) The concrete faces with tie bars shall be scabbled/sandblasted to give a rough key to the new concrete. The pit shall be filled with the approved concrete mix, compacted and textured to match the surrounding slabs. Before concreting the bottom and sides of the pit are kept wet for few hours (not less than 4 hours). The condition of surface should be Saturated Surface Dry (SSD). Some agencies use cement: sand 1:1 slurry with w/c ratio not more than 0.62 to coat the sides and bottom of pit (the slurry should not be allowed to dry). While pouring fresh concrete, it shall be placed in central portion of the pit first and then worked towards edges ensuring complete vibrations including in the corners.

5.6.4 *Layout for repair of deep longitudinal cracks*

The layout recommended for repair of deep longitudinal cracks again depends on the location of the crack with respect to the joints and free edges as per **Fig. 5.6**. Stitching or partial depth patching may be tried depending on the severity of the defect and behavior of the repair under traffic. Continuous longitudinal cracks intersecting with formed or sawn joints are again not acceptable in new construction and all the slabs affected should be replaced prior to "Taking Over" or repair may be carried out as per advice of Engineer-in Charge.

- d) If the repair extends up to the slab joint insert a piece of oiled shuttering ply in the adjacent joint(s) to avoid percolation of patching material in the joint.

5.8 Saw Cutting and Lifting Procedure for Full Depth Repair and Whole Slab Replacement

It comprises of the following procedure:-

- The marked area is sawn with diamond blade saw in pieces or whole according to availability of crane or other machinery to lift and remove slab pieces as shown in **Fig. 5.8**.
- The remaining pieces of slab left over tie bars and dowel bars is broken in such a way that the concrete in the adjacent good slab is not damaged.
- Lifting the whole piece of concrete imparts no damage to the sub-base and is readily done. This method requires less labour than breaking the concrete before removing. Different types of equipment can be used to lift the slab or slab portion by means of a chain connected to lift pins: torque claw attachments for front-end loaders, forklift devices and vertical bridges.



(a) Saw Cutting



(b) Breaking Out by Jack Hammer after making Two Parallel Saw Cuts

Fig. 5.7 Saw Cut and Break Procedure Illustrated



(a) Saw and Break Procedure



(b) Saw and Lift Procedure

Fig. 5.8 Saw Cut and Lift Procedure Illustrated

5.9

Work Safety and Traffic Diversion

- a) Before the repair work is carried out, the proper traffic diversion shall be planned and implemented in consultation with the Engineer-in-Charge having full regard to the statutory and contractual provisions for safety.
- b) All signals required for traffic diversion and work safety shall be brought to the site and placed at appropriate sections and distances.
- c) When the work is finished and curing completed all debris and traffic control measures shall be removed and normal traffic conditions restored (For details refer Chapter 15).

5.10

Disposal of Dismantled Materials

The concrete dismantled during partial depth repair/full depth repair/grinding and grooving shall be suitably disposed off as provided in the contract. In absence of any such provisions the MoRT&H specification clause 202 and IRC:121 should be followed. That is:-

- a) The concrete should be broken to sizes not greater than 0.02 cum and stacked neatly in the ROW (Right of Way) for later reuse or till it is finally disposed off as per contract.
- b) The chunks should be sorted into range of sizes, with larger chunks (less than 0.02 cum in size) broken further by hand or put in the crusher to break them into smaller size particles so they can be reused as an recycled aggregate for nonstructural purpose. For example it can be:-
 - Used in GSB by mixing 20% - 25% of the broken particles (75 mm down) with new material if required after satisfying necessary laboratory tests in the layer concerned.
 - Mixed with gravel/moorum mixture for protecting the earthen shoulder after satisfying necessary laboratory tests.
 - Used in the Dry Lean Concrete (DLC) or foundation levelling course (up to 10) after satisfying necessary laboratory tests.
 - Used for the mechanical stabilization of weak soils after satisfying necessary laboratory tests.
- c) Any unused material may be auctioned or disposed of according to the environmental rules and instructions of the Engineer.

6 CRACK SEALING AND JOINT RESEALING

6.1

General

6.1.1 This is a frequently applied preventive repair technique normally used as a part of periodic maintenance. If the edges of the crack are severely broken (spalled) the slab should be cut 30 mm deep on both sides of the crack at a distance of 10-12 mm each side. The concrete is removed between the cuts and the crack is filled with a fine epoxy resin mortar.

The pit is cleaned and prime coat is applied on sides and at the bottom of the pit. The pit is filled with Epoxy Concrete with 10 mm down aggregates. The cuts have dried as shown in **Fig. 6.1 (b)**. Crack widening and sealing follows the same work procedure as joint grooving and resealing.

6.1.2 Different methods to seal and patch cracks are illustrated in **Fig. 6.1** and are briefly described below:

- a) **Gravity application of low viscosity epoxy resin:** Cracked area is first cleaned by blasting with air. A low viscosity, free flowing, fast curing epoxy resin can be applied from a plastic beaker or from end of a nail by gravity into cracks 0.5 mm- 5 mm wide to secure broken concrete pieces together to prevent it from breaking out. Epoxy resin to be used should be with viscosity in range of 300 centipoise @ 20°C and 110 centipoise @ 30°C. **See Fig 6.1 (a).**
- b) **Epoxy Resin Injection:** Resin injection can be used to make structural repair of deep cracks, particularly corner breaks, by following the method described in MoRT&H Specification. The resin is injected at high pressure in previously bored holes along the crack. The resin fills the crack and sometimes the interface of the slab with the sub-base if the pressure is maintained for a long period. The broken slab is thus secured together and better supported by the sub-base. **See Figs. 6.1 (b) and 6.1 (c).** Care has to be taken not to fill the adjoining construction joints with resin.
- c) **Retaining as a "Working Crack" with Elastomeric Sealant:** Suitable as a short term measure at cracks which do not display faulting and rocking under the traffic load. Route along the crack to provide a uniform groove and apply an elastomeric sealant. The life expectancy will generally depend on the volume of the traffic and the condition of the sub-base.

6.1.3 Overfilling of cracks or joints should be avoided as the residue will struck to the tyres of the vehicle which often leads to uprooting of entire sealant. This can be prevented by bevelling the edges of the joint. This will also eliminate edge spalling (FOD).

6.1.4 Crack sealing between untied/bituminous shoulder shall be filled with a mixture of emulsion rejuvenator and topped off with sand.

6.1.5 Low viscosity epoxy shall also be poured along the boundaries of the patch thus repaired with epoxy/epoxy mortar/epoxy concrete. Dry fine sand shall be spread over these. Different methods to seal/cracks are given in **Fig. 6.1**.



(a)



Pouring Low Viscosity Epoxy Resin

(b)

Treatment of Shallow Spalling at Joints by Gravity Sealing with Low Viscosity Epoxy

(c)

**Fig.6.1 Treatment of Cracks with Epoxy Resin Formulations**

6.2 Joint Resealing

6.2.1 Over time all types of joint sealants suffer distress. They lose flexibility, bond to the walls of the joint groove and may crack. The sealant may be subject to very harsh conditions. Accordingly the material selected for joint sealing, shall be capable of:

- (i) Withstanding horizontal extension and compression and vertical shear;

- (ii) Withstanding climate effects such as weathering by UV rays in some sealants, extreme temperatures and moisture;
- (iii) Resisting penetration by stones and sand at high temperatures;
- (iv) Maintaining strong bond to concrete sidewalls at specified temperatures.
- (v) The sealants (polyurethane/silicone), should pass the hydrolysis test.

6.2.2 Joints shall be resealed as necessary to minimize both infiltration of runoff water in the pavement structure and ingress of incompressible material in the joint groove as shown in **Figs. 6.2 & 6.3**.

6.2.3 The commonly used sealant materials applicable specifications, the designed extension, shape factor and relative price are listed in **Table 12.6** of Chapter 12. The manufacturer's specifications shall be consulted to check the required maximum allowable service extension that the sealant material can sustain without damage and if a primer is required to improve the bond between sealant and concrete.

6.2.4 The joint groove dimensions should be selected after determination of the expected joint movement resulting from temperature changes. The shape factor is defined as the ratio of depth to width of sealant in the joint groove. Too narrow grooves may originate extension failure of the sealant or loss of bond with the groove walls. Manufacturers of silicone sealants recommend a minimum thickness of 6 mm and a maximum thickness of 13 mm because wider joints are prone to spalling. For narrow joints compression seals may also be used as per clause 8.1 of IRC:15 (EVA and PE) apart from other pouring sealant.



Fig. 6.2 Joint Resealing

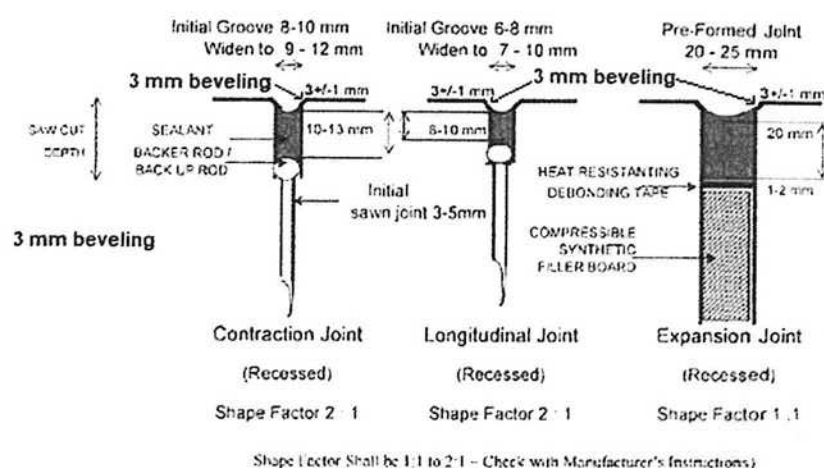


Fig. 6.3 Typical Detail of Field Moulded Joint Sealants

6.2.5 The groove saw cut depth must provide for the sealant depth, the compressed backer rod thickness, and the depth that the sealant surface is to be recessed and extra depth to account for variability of the saw depth as shown in **Fig. 6.3**.

6.2.6 The service life of joints depends on the care taken to prepare the joint and install the sealant. The service life of joint seals also varies with the type of sealant. A typical hot-pot sealant provides an average of 2 to 3 years of life after proper installation. Some low-modulus or PVC and coal tars can perform well past 8 years. Polysulphide sealants perform well for up to 4 to 5 years according to experience on the National Highway Development Project (NHDP) date. Silicone sealants perform well for periods exceeding 10 to 12 years.

Compression seals normally provide service for periods often exceeding 15 years and sometimes 20 years. Further study of the issues of adhesion, temperature, UV radiation and theft (theft due to improper application of seals & poor quality of adhesive) is required here in India. But the most important condition is that the joint be clean and dry when reapplying the sealant (adhesive in case of compression seals). Also, some materials are unsuitable for bonding to fresh concrete and so technical advice should be sought from sealant manufacturers regarding the recommended minimum concrete age at the time of installation. Normally it is not before 21 days of paving.

6.2.7 Joints sealants should be replaced when they are defective or reach the end of their service life and do not prevent ingress of water any more. Simply pouring new sealant in the old joint will not restore the latter. The old joint shall be completely removed, the joint groove cleaned and groove walls to be roughened and the new joint material properly placed, after priming as per manufacture's instructions. This work must be performed under dry condition and preferably scheduled in the hotter months of the year.

6.2.8 When the joints are spalled, compression seals should not be used before its proper repair because they would tend to twist or move up and down in the joint at locations where the joint walls are not vertical and uniformly smooth. (After repairing the spalled portion, compression seal can be used for resealing of joints).

6.2.9 The sealant is applied after insertion of a backer rod in the groove. Backer rod keeps off the fluid sealant from sinking in the groove and bonding to the bottom of the groove (Prevents

3 point adhesion). They shall be flexible, compressible, undergo no shrinkage, repel water and not react with the sealant. The rod diameter should be at least 25% larger than the joint width, so that it fits tightly in the groove.

6.3 Method for Repairing the Flexible Joint Sealant

- (1) Select the material and method of applying the liquid sealant, taking necessary approval from the Engineer-in-Charge.
- (2) Materials from the compression joints can be removed manually by pulling out after cutting it by 0 running a knife blade along the faces of the wall or running a saw cutting machine with worn/used blades or by ploughing. Most sealants can be very effectively removed by ploughing (raking). V -shaped plough/rake should not be used. Rectangular plough/rakes cause very little damage to the joint groove faces. The plough/rake should pass at least twice cleaning one joint face during the first pass and the other joint face during the second pass. Ploughing should remove at least 95% of the old sealant material.
- (3) Joint materials are removed and disposed properly. Some materials may require hazardous or specialised waste disposal methods.
- (4) Width of groove and shape of the groove is improved for the new material as per provision of IRC:57. The groove shall be shaped by sawing with a diamond blade. This is an efficient method for ensuring complete removal of old sealant. Reshaping the old groove may be required for improving or modifying the shape factor and can be done by cutting with dry or wet diamond blades. In many cases blades are ganged side by side on the blade arbour with a metal spacer to allow the saw to reface both joints to a uniform width in one pass. However, some sticky sealants such as PVC and coal tar can clog the diamond blade. The refacing of the groove shall be kept to an absolute minimum in order to keep the joint groove from becoming too wide, which may lead to risk of extra damage and spalling at the joint.
- (5) Edges of the joint groove are chamfered to improve the durability of the sealant and the profile (**Fig. 6.4**). Minor spalls along the joint faces do not inhibit performance of most sealants but some patching may be needed for larger spalls. These spalled grooves shall be patched before proceeding with groove cleaning.

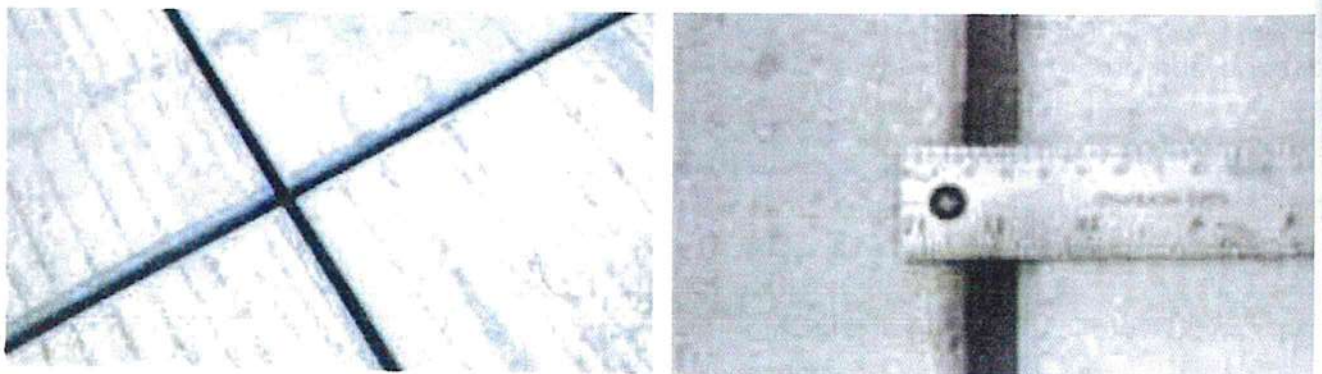


Fig. 6.4 Beveling/Chamfering of Joints

- (6) The groove faces of the joint are cleaned thoroughly. This is the most important task of joint sealing. Groove faces require a thorough cleaning to ensure sealant adhesion and long term good performance. Dirt, dust or traces of the old joint material shall not remain on the joint faces after cleaning. Joints wider than 10 mm are easy to clean. Cleaning of narrow joints of 6 mm width or less is very difficult and shall be carefully performed.

Note: Using chemical solvents for cleaning is not allowed because they can leave contaminants in the pores of the groove faces that will inhibit bonding of the new sealant. Proper cleaning combining mechanical action with water flushing is required.

- (7) The saw slurry and any cleaning chemical residues shall be washed away immediately after sawing in a single direction.
- (8) The groove faces are sandblasted one by one when the joint is dry. The sandblast is done by holding nozzle close to the surface at an angle with the surface. Sandblast removes residues of the old sealant and provides surface texture to improve sealant adhesion. Alternatively when compression seals are to be used the sidewalls may be prepared by grinding or wire brushing.
- (9) The joint and pavement surface is air blasted to remove any remaining sand and dust, ensuring the compressor is blasting clean air without oil contamination prior to air blasting. If not, an oil and moisture filter is required or the insertion of oil in the air by the compressor shall be discontinued.
- (10) The surrounding pavement is kept clean by use of a vacuum sweeper or broom.
- (11) The compressible backer rod is installed to give the correct shape and depth to the sealant. The backer rod material shall be compatible with the liquid sealant and have a diameter about 25% larger than the groove width. Backer rods shall be forced into the groove uniformly to the desired depth. Many methods have been used including poking in with a screwdriver that may damage the surface of the rod and automated equipment. The best tool is the steel or non-metallic roller with two lateral wheels supported by the pavement surface and a central insertion wheel that can be changed to match different depths. Good practice is to roll the insertion wheel over the Backer Rod twice in opposite directions.

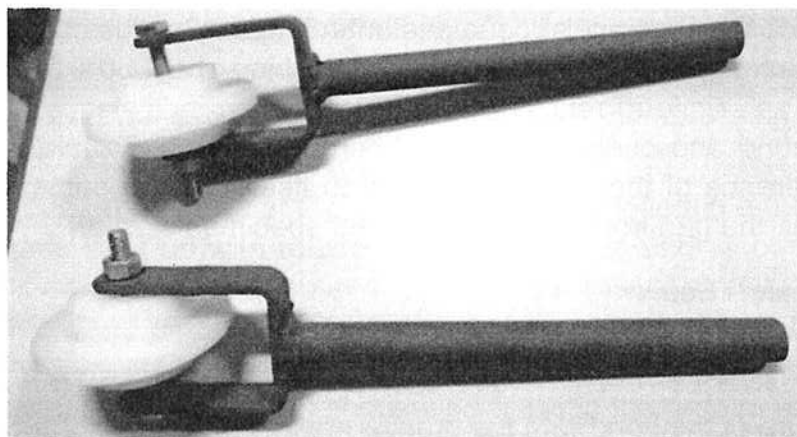


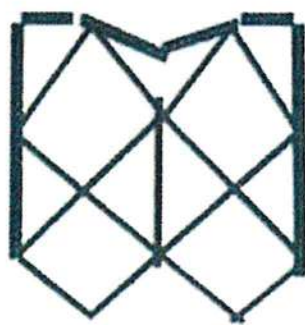
Fig. 6.5 Tool for Inserting Paper Backup Strips or Backer Rod into Joint Groove

- (12) Groove sidewalls are checked that these are free of dust and dirt before pumping/pouring the sealant. The joint should be cleaned again if any traces of contamination are found.
- (13) The primer is applied to the dry side walls of the groove according to the recommendations of the manufacturer. The durability of priming depends on climatic conditions. Ref IRC:57
- (14) Installation requirements are different for each type of sealant. Recommendations from the concerned/selected manufacturer should be followed. Manufacturers also provide mobile equipment to melt and pump the hot sealant into pavement joints and also to apply cold applied sealant material.
- (15) The liquid joint sealant is installed at the proper temperature recommended by the manufacturer. When the sealant is at the right temperature about 250 ml (1/4 litre) of cold sealant should be discarded from the pumping unit hoses and nozzle before installation begins. The nozzle shall be introduced in the groove to fill the sealant from bottom and reduce chances of entrapping air. Instead of pushing the nozzle, the operator shall draw it towards himself to achieve a more uniform cross section and less voids. The groove shall not be filled to the top. The sealant surface shall be recessed 2 ± 1 mm from the pavement surface. Tool the polysulphide sealant with a wooden spatula after 10 minutes and then apply more sealant, if needed. The nozzle shall be sized to match the groove width and no moisture should be allowed in the latter.
- (16) Low-modulus silicone sealants are not self-levelling and require tooling within 10 minutes of installation before they begin to "break/cure" and form a skin. A tool or a backer rod strip is drawn over the fresh sealant to force it in contact with the sidewalls at the top of the groove and produce a concave shape.
- (17) Moist grooves shall be previously first dried to avoid boiling of water in contact with the liquid sealant which may inhibit adherence.
- (18) When transverse joints are sealed with silicone and longitudinal joints are sealed with hot pour sealants, silicone shall be applied first because it is viscous and will only slightly penetrate the longitudinal joints.
- (19) Finally check sealant adhesion to the sidewalls by pushing down a knife blade along the groove sidewalls.
- (20) Check the curing of silicone sealant after 2 to 3 weeks by removing a small 50 mm long specimen of sealant and stretching about 50% for 10 seconds. A fairly fast and uniform relaxation of the specimen indicates adequate curing. Slow rebound and curling indicates differential curing. To take advantage of good adherence of the silicone material to itself use the same brand of sealant to repair the gap from which the sealant specimen was cut.

6.4 Compression Seals

6.4.1 Defects in compression seals generally comprises:

- a) Failure of the bond with the groove walls
- b) Pulling out/theft by vandals



a) Typical cross-section of Compression Seal



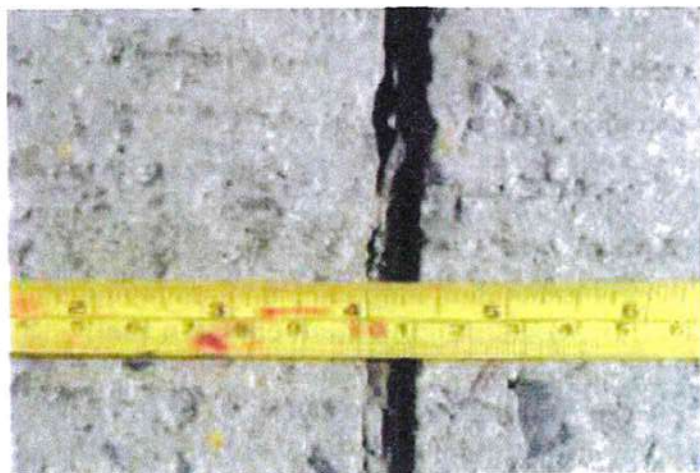
b) Loosening of Compression seal

Fig. 6.6 Compression Seals

6.4.2 Reinstatement of compression seals comprises of the following:

1. The joint side walls are inspected for raveling, spalling and other irregularities that could reduce the seal's lateral pressure and originate seal extrusion or popping out from the joint. Repair damaged sections before installation of the compression seal.
2. Any burrs along the sawed joint are removed by dragging a blunt, pointed tool along sawed joints. This removes sharp edges which if left untreated may make the seal installation difficult. A mechanized wire brush can also be used for this purpose.
3. This type of operation shall be done only where needed and before cleaning the groove.
4. Lubricant/adhesive is applied to the seal edges and/or groove sidewalls.
5. The compression seal as shown in **Fig. 6.6 (a)** is installed taking care not to stretch the seal more than 2-3% during installation. Stretching by more than 5% could be detrimental and later on may cause sealant to break into pieces. Special attention shall also be paid to avoid twisting and nicking in addition to stretching. To monitor sealant stretching lay a length of sealant parallel to the joint and cut a piece of seal with the same length. The piece of seal is extracted and its length is measured after relaxation, stretch in percent is calculated.
6. Improper adhesive may cause failure of compression seal as shown in **Fig. 6.6 (b)**.

6.4.3 The **Fig. 6.7 (a)** shows that the liquid sealant has failed in adhesion and is missing in parts. This gap gets filled up with refuse, dust, aggregates and all other filthy materials. If movement is restricted or materials enter the joints, excessive stress develop, resulting in development of defects and plying of traffic further enhance the problem. Due to these unfilled open joints, potholes may start developing leading to the spalling of the transverse joints and cracks at joints. **Figs 6.7 (b)** and **6.7 (c)** show sand blasting the groove walls and subsequent clearing with compressed air jet. **Fig. 6.8** shows further pictures in sequence of the method for repair of joint sealants.



a) The Liquid Sealant Adhesion Failure



b) Sand blasting the groove after raking out the sealant residue and rubbish from the joint.



c) Compressed Air used to clean

Fig. 6.7 Preparation for Joint Resealing



a) Typical cross-section of Compression Seal



b) Loosening of Compression seal

Fig. 6.8 Baker Rod Insertion into the Joint Groove

7 CRACK STITCHING (CROSS STITCHING)

7.1 General

7.1.1 Crack stitching with inclined tie bars (cross-stitching) or U-bars (stapling) may be used for full depth longitudinal cracks in reasonably good condition i.e. the width of crack is less than

3 mm and length is more than 1 m in order to arrest movement of slabs and slab pieces. Stitching maintains aggregate interlock, prevents the crack from vertical and horizontal movement or widening and provides added reinforcement and strength. **Table 4.5** shall be referred to for selecting suitable cases for this type of repair.

7.1.2 Cross-stitching serves the same purpose as tie bars and bent tie bars (stapling) but requires less surface disruption than the installing tie bars.

7.1.3 Cross-Stitching shall not be used as an alternative for treating cracks that are severely deteriorated/spalled. It is normally used for the treatment of narrow longitudinal and diagonal cracks which do not display spalling or other types of distress. Full depth transverse cracks which have assumed the role of an adjacent joint should not be stitched. Stitching will not allow joint movement (open and closure), so a new crack is likely to develop near a stitched working crack or the concrete will spall over the reinforcing bars and along the crack. For safety measure, the longitudinal joint(s) adjacent to the cross stitched slab, should be cleaned thoroughly and resealed for effective joint movement. In such cases otherwise, dowel bar retrofit, full depth repair or whole slab replacement should be used depending on alignment and position of the crack.

7.2 Methodology for Cross Stitching

The cross-stitching procedure is illustrated in **Figs. 7.1 & 7.2**. The same is as follows:

- (i) Preliminary vertical holes (diameter $\varnothing = 36 - 45$ mm), 30 mm deep are drilled in an alternating pattern at 500 mm - 750 mm spacing apart, where the inclined hole starts to facilitate its drilling.
- (ii) Alternate inclined holes (12 to 20 mm) at an angle of about 30° to 40° from the slab surface normal to the line of the crack are drilled; the length of the holes shall be equal to 1.7 times slab thickness. The holes should be spaced as for (1) above and alternate from each side of the crack. Whilst a 500 spacing is generally recommended, a 750 mm spacing is adequate for light traffic and lightly loaded inner highway lanes. For heavy traffic and outer lanes, a spacing of 500 mm c/c is preferred. The dimensions and spacing also depend on the slab thickness in a similar manner as dowel bars.
- (iii) The holes are cleaned thoroughly using oil-free compressed air.
- (iv) The hole is filled with epoxy resin/elastomeric concrete in enough quantity for the bar to be completely coated when inserted in the hole.
- (v) A high yield deformed epoxy coated reinforcing bar (12-16 mm) is placed conforming with IS:1786 & IS: 13620 in every hole.
- (vi) A groove shall be made along the line of cracks displaying spalling and filled with a low viscosity resin, fine epoxy mortar or elastomeric cement as appropriate as per Para 6.1.1.

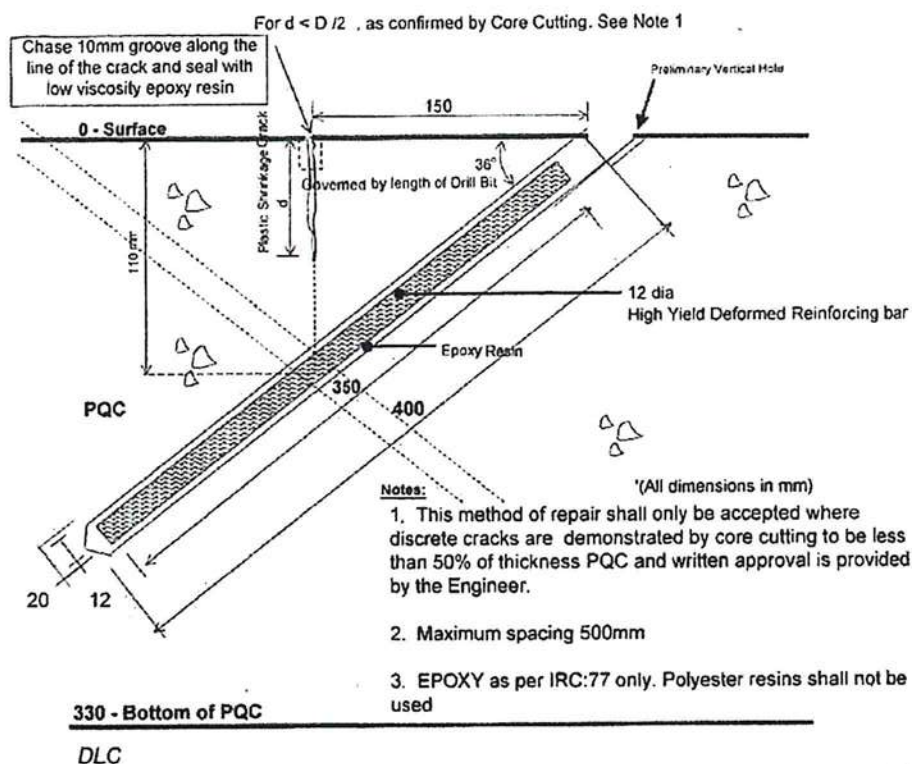


Fig. 7.1 Typical Arrangement for Cross Stitching with 12 mm Dia Straight Bars



Fig. 7.2 Drilling Inclined Holes with Angle Template

7.3 Methodology for Stapling

Stapling or slot stitching is a technique used to provide positive mechanical interconnection at longitudinal crack or joint between two slabs or segments. 16 to 20 mm dia epoxy coated U-shaped deformed bars placed in the slots hold the segment together, serving to maintain aggregate interlock and provide added reinforcement and strength (Fig. 7.3). These bars prevent further migration of slabs. Larger diameter bars may also serve the function of load transfer. The procedure for the same is as follows:

1. Mark the position of vertical holes of dia 30 mm at a distance of 228 mm from the crack at a spacing of 600 mm c/c.

2. Drill 30 mm dia holes upto maximum depth of $D/2$.
3. Cut the slots of 30 mm width and of a depth of 50 mm less than the depth of drilled holes.
4. Remove debris and clean the slots and the holes.
5. Roughen the sides of holes and slots by sand blasting/sand paper.
6. Insert U-shaped deformed steel staple bars into the slots and anchor the ends into holes with high modulus epoxy.
7. Fill the slot with 1:3 epoxy-sand mortar or elastomeric concrete upto 10 mm above the top surface of staple bar. Vibrate or tamp the mix to ensure proper compaction of the material surrounding the staple.
8. Fill the remaining volume of the slot with non-shrinkable concrete or any other equivalent material upto the top level of PQC and finish it properly.



(a) Slot Cutting and U-Shaped Staples



(b) Slot Filled with Elastomeric Concrete

Fig. 7.3 Stapling of Longitudinal Joint

7.4 Methodology for Slot Stitching

Slot-stitching (**Fig. 7.4**) is a repair technique for longitudinal cracks and joints. It provides mechanical interconnection between two slabs or segments on opposite sides of longitudinal joint or crack respectively. The deformed steel bars placed in the slots not only hold the segments together to maintain aggregate interlocking but also provide added reinforcement and strength to the joint or crack. Bars provided into slots also prevent horizontal and vertical movement of segments at crack or joint. Larger dia bars (> 25 mm) also help load transfer across the joint or crack. Slot-stitching involves the following steps:

1. Cut slots approximately perpendicular to the longitudinal joint or crack using a saw cut or any other machine.
2. Remove the concrete and clean the slot. Prevent concrete debris from entering into the joint or crack.
3. Place deformed 16 mm to 20 mm dia bars into slots.
4. Fill the slot with non-shrinkable or very low shrinkage material.
5. Finish flush with the surface and cure as per the curing instructions for the material.



(a) Slot Cutting



(b) Slots Filled with Non-shrinkable Material

Fig. 7.4 Slot Stitching of Longitudinal Joint or Crack

7.5 Cross Stitching Vs Slot Stitching

Both the methods of cross stitching and slot stitching are effective in preventing the widening and maintaining aggregate interlocking at longitudinal joint or crack. However, cross stitching has following advantages over slot-stitching:

- Cross stitching is less intrusive and less damaging to the slab.
- Repaired surface area exposure is less. Only drilled circular holes are visible on surface.
- Quantity of backfill material is less.

Thus, cross-stitching is less expensive repair option than slot-stitching. However, the selection of repair methodology should be evaluated on the basis of strength, installation time and cost at the project site.

As mentioned before after crack stitching, it is very important to treat the adjacent longitudinal joint. If there exists a functional crack in the joint, the joint needs to be cleaned, treated for any spalling and resealed. In case of drifted slabs, the joint shall be filled with suitable fillers to avoid through penetration of water, a compressible filler board may be compressed & inserted in the joint along with a cement grout. Photographic process illustration

8 PARTIAL-DEPTH REPAIR

8.1 General

Partial-depth patches are provided for majority of surface distresses at joints, cracks, and mid slab locations that are within the upper half of the slab. The most common distress type requiring partial-depth repair is spalling as shown in **Fig. 8.1**, but partial-depth repair can also be used for restoring small areas like popouts, potholes and corner breaks as shown in **Fig. 8.2**. **Table 4.5** shall be referred to for selecting suitable cases for this type of repair.

For severe, shallow and surface defects, spalling is typically a random and localized distress. Surface spalls create a rough ride and can accelerate development of further distress. Partial-

depth patches replace unsound concrete by fresh concrete to restore surface evenness and arrest further deterioration. They also provide proper edges for resealing joints and sealing cracks & reduce occurrence of Foreign Object Damage (FOD).

Joint edge spalls mostly result from poor workmanship (compaction and or finishing) whilst starting the next day's work at a construction joint, penetration of incompressible materials in the joint groove and slab curling and warping, dowel bar lockup, dowel bar out-socketing or when reinforcement is too close to the surface of the pavement. Partial depth patching can only repair spalls in the upper half of the slab, when load transfer devices, dowels are in good condition.

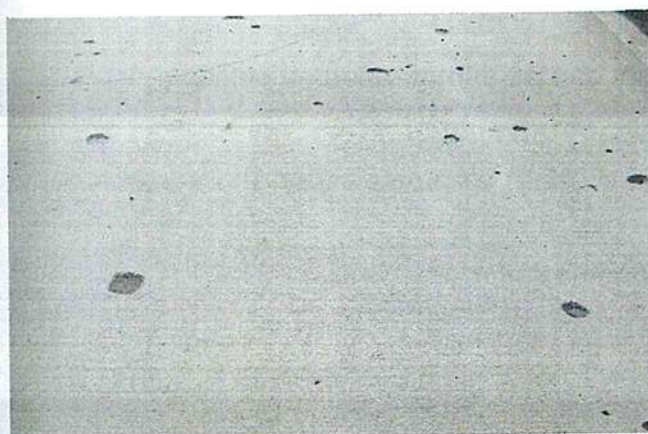


(a) Spalling at Joint



(b) Spalling at Crack

Fig. 8.1 Typical Spalling at Joint and Crack



(a) Popouts



(b) Corner Break

Fig. 8.2 Typical Popout and Corner Break

8.2 Selection of Repair Material

Material selection for partial-depth repairs should consider the following factors: mixing time and required equipment, working time, temperature range for placement, curing time, aggregate requirements, repair area moisture conditions, cost, repair size, and bonding requirements. The choice of materials should be such that, it should serve the purpose with prolonged strength & functionality in the most cost effective way. Typical properties of cementitious repair materials are given in **Table 8.1**. Refer Chapter 12 for more information.

Table 8.1 Typical Properties of Cementitious Materials at 25°C with W/P (Part A) Ratio of 0.22

PROPERTY	TEST METHOD	VALUE
Component		Two: Part A- Fine Powder Part B- Coarse Aggregates
Mixed Form		Workable Concrete
Colour		Grey
Fresh Wet Density	BSEN 12350-6	2.4 kg/ltr +/- 0.05
Working Time		15 mins
Setting Time		30 mins
Compressive Strength	ASTM C109	3 hrs - 12 N/mm ² 1 day - 25 N/mm ² 28 days- 40 N/mm ²
Bond Strength	ASTM D4541	> 2 N/mm ² at 28 days
Flexural Strength	BS 6319-3	> 4.5 N/mm ² at 28 days
Water Absorption (ISAT)	BS 1881-208	< 0.01 ml/m ² /sec at 2 hrs
Drying Shrinkage	ASTM C157	< 400 microstrain at 28 days

8.3 Methodology for Partial Depth Repairs (PDR)

Partial depth repairs can be used for repair of Potholes, Popouts, Corner Breakage, Edge Breakage, Joint Spalling or any other type of surface defect which may be encountered in rigid pavements.

The standard methodology for partial depth repairs can be summarized as below:

- i) Identification & Marking out of Repair Boundaries
- ii) Removal of affected concrete
- iii) Cleaning & Preparation of Patch
- iv) Application of Pre-coat/Primer/Bonding Agent
- v) Placing & Finishing of Repair material
- vi) Application of Seal Coat
- vii) Curing of Repair Patch
- viii) Joint Re-sealing
- ix) Allowance of Traffic

(i) Identification and Marking of Repair Boundaries

Before commencement of work, the general survey of repair area should be done. The affected area is checked for extent of spread of unsound concrete either by using steel rod/hammer sounding test or by running a heavy steel chain across the affected area. The unsound concrete produces a hollow or dull thud whereas sound concrete shall produce a sharp metallic ring with adequate rebound. The limits of unsound concrete are fixed using this method. The boundary of the proposed cut is fixed 50 mm deep in the sound concrete so as to ensure that no unsound concrete is left out.

Partial-depth patches are usually very small. Each patch usually covers an area less than 1 m^2 . The area to be repaired as stated earlier, shall extend 50 mm beyond the limits of unsound concrete generated by hammer sounding survey and be at least 100 mm x 250 mm (in plan) x depth of patch/minimum depth. The depth is normally in the range of 65 mm (+/- 15 mm) for epoxy mortar/polymer/elastomeric concrete type repair or 40 mm deep (+/- 10 mm) for elastomeric concrete (See **Fig. 8.3**). For depth more than 80 mm, the patch should be repaired with M 30 grade Concrete made with 10 mm down aggregates. Shallower patches have a tendency to break up and breakout under traffic. Small steel studs cut from reinforcing bar may be drilled and epoxied into place in an approximate grid pattern (100 mm x 100 mm) to provide an extra key effect similar as shown for the treatment of popouts as shown in **Fig. 8.4**. The repair boundaries should be kept square or rectangular and irregular shapes should be avoided.

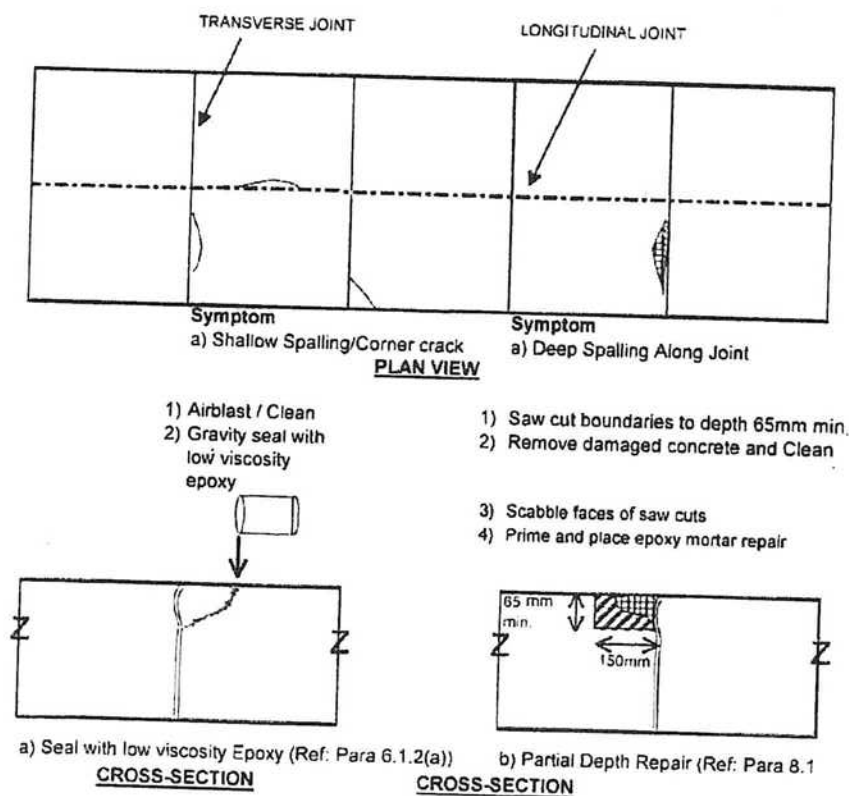


Fig. 8.3 Repair of Shallow Cracking and Spalling Near the Joints

(ii) Removal of Affected Concrete

The removal can be accomplished either by saw & chip method or by cold milling the affected portion. In saw & chip method, the upper 50 mm of the concrete (or deeper if the spall is wide but not deeper than one third of the slab thickness) is saw cut parallel to the joint on the perimeter around the repair area. In case one of the patch area faces is a sealed joint, the saw should be run through the sealed joint to obtain a clean vertical surface for repair. Additional cuts may be made within the repair area to speed up chipping. The concrete should be removed with an electronic chipper/hammer not more than 10 Kg in weight. The area upto the bottom of the cut patch shall be chipped and removed. The repair area is chipped about 10 mm deeper into the sound concrete. After finishing of chipping the debris shall be removed and the patch shall be inspected using hammer sounding test to check for any more unsound concrete faces.

In case the spalls are observed to extend beyond half depth of pavement or to full depth of the pavement, the patch should be fixed using full depth repair technique. The patch shall not expose any dowel bar or reinforcement. If a dowel bar or reinforcement is exposed the surrounding concrete shall be completely removed to at least 25 mm below the bar or wire as shown in **Fig. 8.3** for typical layouts. The upper/unsound concrete layer between the joint and saw cut is chipped out; by manual or mechanical chipping. Loose materials is removed from the pit of the patch and clean the repair area.

(iii) **Cleaning and Preparation of Patches**

The pit surface is cleaned eliminating all dust and exposing the concrete grain texture: (a) check the air blown by the compressor for oil and moisture with the help of a cloth; (b) sandblast the surface to remove dirt, oil, residual unsound concrete and laitance and to improve texture; (c) air blast the surface to complete cleaning; (d) check the prepared surface for cleanliness by rubbing across with the hand or a cloth; if the pit is not immediately patched, cleaning operations shall be repeated. As a minimum, the patch should be air blown, cleaned using high pressure water jet & then dry air blown.

The patch pit is again checked for unsound concrete before starting the patch. If unsound concrete is detected it should be removed and the pit cleaned again by air blasting.

During spall/corner break repair, the existing joint groove shall be protected against leaking of fresh resin or cement mortar repair compound that could build bridges between the two slabs. If non flexible patch material is used an oiled piece of ply-board or a compressible synthetic filler board of thickness that can be compressed to the pre-existing joint width be placed to form a bond breaker in the adjacent joint(s) to avoid penetration of patching material in the joint. The bond breaker should be inserted 25 mm deeper than the patch, have the same upper level as the slab and a scored top strip. Laterally the bond breaker should extend 75 mm on both sides of the patch. The bond breaker should be slightly thicker than the joint opening and be slightly compressed after installation. Latex caulking can be used to seal any gaps between the bond breaker and the joint opening.

(iv) **Application of Pre-Coat/Primer/Bonding Agent**

This is the most critical process that governs the bonding of repair compound with parent concrete. The bonding agent (water-cement slurry, resin etc.) is mixed carefully according to the manufacturer's instructions. The bonding agent is applied using a hard bristle brush to the walls of patch area, evenly in a uniform coat & it should not be allowed to collect in pockets. The bonding agent should be in appropriate consistency/tacky when the patching operation starts. Some special kind of propriety materials do not require application of bonding agent prior to placing of patch material.

(v) **Placing & Finishing of Repair Compound**

The patching mix is prepared using a small drum or paddle-type mixers with capacity of about 0.2 m³. A small Jiffy mixer may be used for smaller patches. Aggregates and binder may be previously weighed and bagged. Mixing times and proportions are strictly observed. Too long mixing will reduce the time that is available to patch.

The patch materials are placed by slightly overfilling the pit to allow for volume reduction during compaction/screeding. Aggregate mixes shall be placed with a shovel, because dumping from buckets or wheelbarrows causes segregation. Cementitious mixes shall be vibrated to release entrapped air. The vibrator shall be held at 15°- 30° from the vertical and lifted up and down until the whole patch is covered. It should not be moved horizontally in the patch. Some patches may be too small for the use of internal vibrating needles and vibrating screeds. Rodding and tamping or cutting with a trowel or other small hand tool is acceptable. Some polymer mixes including epoxy mixes which have high heat of hydration, should, in certain adverse conditions, be placed in several 38 mm to 50 mm thick lifts with waiting times between lifts as recommended by manufacturers.

The finishing area should be finished to the cross section of the existing pavement without leaving excess material on the adjacent pavement surface. The recommended finishing procedure is to screed/trowel from the center of the patch area to the patch boundaries. By moving the screed/trowel toward the patch boundaries, the material is pushed toward the interface to increase the potential for high bond strength. After finishing, the patch should be textured/tined using brush to approximately match the surface finish of the existing adjacent concrete pavement. For higher accuracy levels, the operation is followed by grinding of the pavement area.

In case there are any saw-cut run outs, they should be filled using the repair material. Leaving them unattended may cause ingress of moisture/water and incompressible materials which shall delaminate and de-bond the patching material.

(vi) Application of Bonding Coat

An important procedure in placement of partial-depth repairs is sealing the patch/slab interface. After the material has gained sufficient strength. The patch/slab interface is coated with 1:1 cement : sand mortar having WC ratio 0.4 to 0.62. This paste will act as a bonding agent between the old and new concrete. After putting the fresh concrete in the partial depth repair cavity the same is properly compacted.

(vii) Curing of Repair Patch

Proper curing of partial-depth repairs is very important due to the large surface of small patches compared to the volume of patch material, as well as the fact that concrete gains bond strength much slower than it gains compressive strength. This relationship is conducive to quick moisture loss and is different from most other concrete applications. Proper curing generally employs the application of curing compound at the time bleed water has evaporated from the surface. Because curing is critical for partial-depth patches, the first 24 hours should be wet cured with gunny bag. Proprietary patch materials shall be cured as recommended by the manufacturers. Some require some type of moist curing whereas others need application of specific curing compounds and a few others may be air-cured.

(viii) Joint Resealing

Resealing the repair joint is important, because it will help prevent moisture and incompressible material from causing further damage. It is important that the new transverse and longitudinal joints constructed within the patch area be formed or sawed to provide the proper joint seal

reservoir, and match surrounding joints. The joint faces must be clean and dry for good sealant performance.

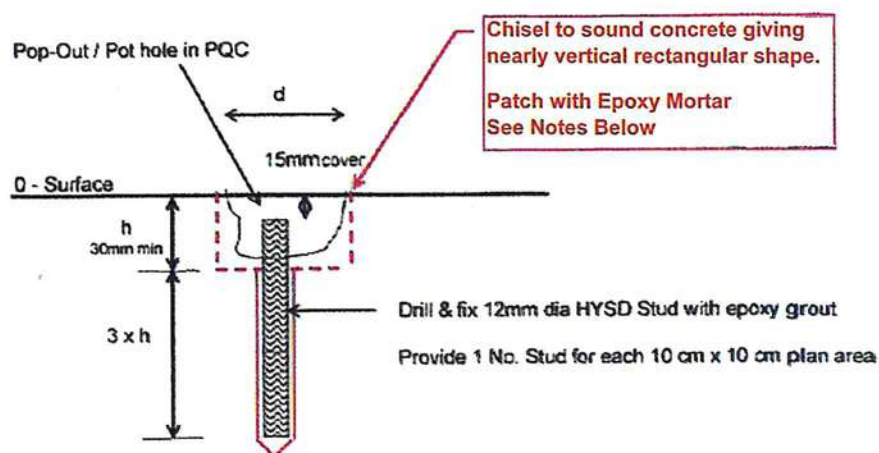
(ix) Allowance of Traffic

Compressive strength requirements for paving concrete are generally specified at M40 at 28 days. The repair concrete should develop an equal or greater strength by the time it receives traffic loadings. However, to minimize lane closures, traffic loadings may be allowed on a patched area when the repair concrete has attained the minimum strength needed to assure its structural integrity. The compressive strength required for the opening of partial-depth repairs to traffic may be lowered because of their lateral confinement and shallow depth.

The specifications of rapid-setting proprietary mixes should be checked for recommended opening times. Cylinders or beams can be tested for strength to determine what opening time will allow the repair material to develop enough strength.

8.4 Methodology for Repairing Popouts

This procedure as illustrated in **Fig. 8.4** excludes saw cutting the boundaries of the patch and is typically required for treatment of popouts/potholes and spalling.



Notes:

- 1) Depth 50mm
- 2) HYSD Studs to be provided with 20 mm cover
- 3) High Early Strength Non-Shrink Grout/Mortar material may only be considered after conducting trial of product (s) proposed by the Contractor.

330 mm TYP - Bottom PQC

DLC

CROSS-SECTION

Fig. 8.4 Methodology for Repairing Popouts

good sealant

The procedure is as follows:

- (i) Chipping starts in the middle of the patch and progresses to the borders. The chipping point shall be directed towards the inside of the patch at about 45°. Hand tools or light electric chiseling machine of 6.8 kg maximum with spade bit may be used.
- (ii) Drill and epoxy grout in stud.
- (iii) Prime with low viscosity epoxy on bottom and vertical sides.
- (iv) Fill the patch with epoxy mortar (1:3).

This procedure has the following advantages:

- a. The rough vertical edge promotes bonding.
- b. There are no saw overcuts.
- c. Fewer steps and smaller crew than for the saw and chip procedure.
- d. Spalling is controlled by using the 6.8 kg jackhammer.
- e. May be faster than the saw and chip procedure if mechanical tools are used.
- f. A saw is only needed for joint sawing, which is a different work.

This procedure has the following disadvantages:

- a. Sound concrete may be damaged by heavy hammers.
- b. Jackhammers can cause feathered edges.

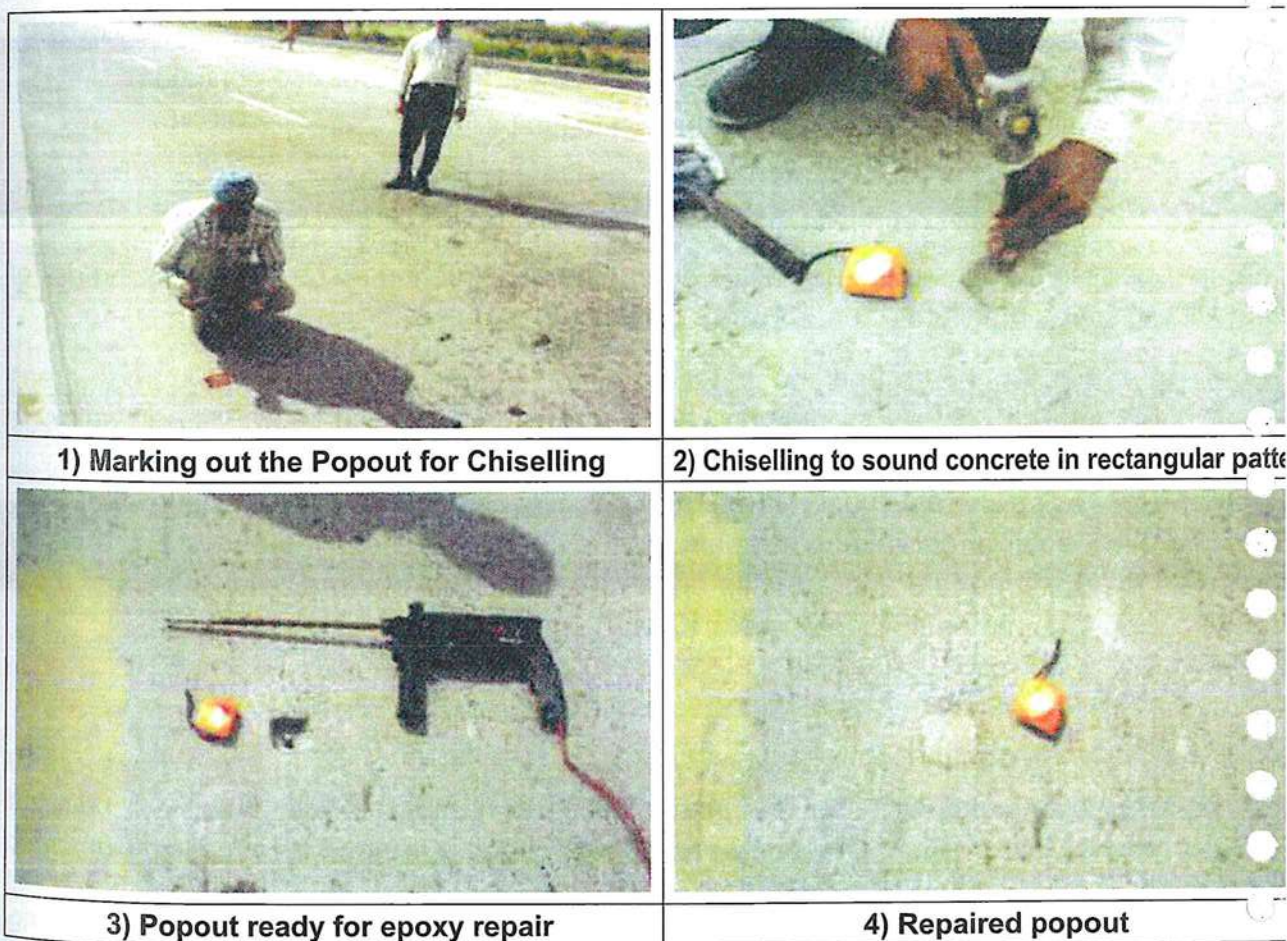


Fig. 8.5 Photographs Illustrating Repair of Popouts

8.5 Potential Problems with Partial Depth Repairs (PDR)

Partial-depth repairs are generally susceptible to failure over a period of time. The causes of failure of partial depth patches can be design, material or construction related failure of a large epoxy patch and cementitious patch.

8.5.1 *Design-related causes of large partial-depth patch failures are the following:*

- a. Exclusion of some deteriorated concrete from repaired area.
- b. Incompatible climate conditions materials or procedures.
- c. Thermal incompatibility between repair mixes and the slab concrete.
- d. Climatic conditions during the service life that are beyond capability of repair materials.
- e. Inadequate cure time after the repair.
- f. Inadequate opening time after the repair.
- g. Incompatibility between joint bond breaker and sealant material.

8.5.2 *Construction-related causes of shallow partial-depth patch failures are the following:*

- a. Failure to square the hole.
- b. Deteriorated materials not completely removed.
- c. Inadequate cleaning, namely laitance (sawing slurry) adhering to surface.
- d. Lack of bond (poor surface coating or inappropriate surface condition)
- e. Failure to re-establish compression failure.
- f. Variability of repair material.
- g. Insufficient compaction of fresh patch mixture.

Full depth repair is the recommended choice during the construction stage for minimizing risk of dealing with this type of failure after 2-3 years traffic or less.

Epoxy mortar is susceptible to brittleness over a period of time when exposed in large areas to UV or direct sunlight. Epoxy mortar may be modified by adding at-least 5% poly-sulphide polymer in the epoxy resin. Such formulation will improve the life of the mortar by giving some flexibility and improving UV resistance. As much as possible cementitious based repair compounds shall be used for repair of partial depth repairs as they do not possess the above problems as encountered in epoxy mortars and are also bond to parent concrete in a better way. For more information regarding materials kindly refer Chapter 12.

8.6 Problem associated with Longitudinal Tining

Tining is the preferred method for texturing fresh concrete. It is generally provided transversely but can be applied longitudinally also. Longitudinal tining is new to India and has been adopted in certain projects under NHDP. Certain observations have been made after passing of traffic after relatively short period of time (less than 4 months). The edges get abraded in the wheel path and shallow spalling develops at irregular interval along the pavement. This affects the surface evenness and riding quality. (Refer Fig. 8.6).



Fig. 8.6 Abrasion in the Wheel Path

9 FULL DEPTH REPAIR

9.1 General

This is the ultimate repair treatment. **Table 4.5** shall be referred to for selecting suitable cases for this type of repair. If this treatment does not succeed an overlay is to be used either along or alone with full depth repair. The procedures to be followed for whole slab replacement are broadly similar to full depth repair as described in this Chapter. Full depth repair may be considered as the preferred repair option in the following situations:

- (i) Partial depth repair has failed
- (ii) The cross-stitched longitudinal joint has again failed
- (iii) The crack which was less than $D/2$ has propagated more than $D/2$ or full depth and the slabs across the crack are rocking
- (iv) The slab has shattered and can no longer support the load of traffic
- (v) The spalling along the joint or crack is more than 50% depth of slab thickness
- (vi) The corner break is down to full depth
- (vii) Failure of pavement due to dowel bar locking and serious cracks along the joint have developed
- (viii) Blow-up at expansion joint.

Full-depth repair entails removing and replacing at least a portion of a slab down up to the bottom of the concrete. Full-depth repair improves pavement surface evenness and structural integrity and extends the pavement service life. The most common problem that requires full-depth repair is cracking full width near the joints and joint deterioration. This includes blow-up and any cracking, breaking, or spalling of slab edges on either side of a transverse or longitudinal joint. Often, spalling takes place on the bottom of the concrete slab and may not be visible from the surface. Spalls that extend 75 mm to 150 mm from the joint are an indication that additional spalling could exist below and would require full-depth patching (Refer **Fig. 9.1**).

Full-depth repair is also necessary to repair any deep corner breaks or any slabs with more than one intersecting full depth crack. The latter may result from lack of uniform support or inadequate structural strength. Most full-depth repairs cover an area of more than 2 m². Their minimum dimension in longitudinal or transverse direction should be 1.5 m. For multiple corner breaks or slabs with intersecting cracks, their size may correspond to the area of an entire slab. Before full-depth patching the sub-base and separation layer shall be reinstated as required. (**Fig. 9.2**)

9.2 Replacement of a Portion of a Slab Comprises the following Tasks:

- (i) The area to be treated is marked according to the guidelines in para 5.6 and 5.7 in Chapter 5. Inspection of the area for unsound & sound concrete should be made by sounding hammer method, by placing a straight edge & checking deflection or by core tests. (Ref **Fig. 9.5**)
- (ii) The materials and procedure are selected for patching in consultation with the Engineer. The patch mixes for full-depth repairs often use ordinary or rapid hardening Portland cement as per the need and also proprietary cement that gain strength early (**Appendix B**). A job mix design shall be tested in the laboratory with a target slump of 20 - 40 mm. To decrease the water-cement ratio a water-reducing admixture plasticizer/super plasticizer may be required for Grade 43 or Grade 53 cement (IRC:44-2017 may be referred for mix design).
- (iii) The portion to be replaced is cut out and removed. The perimeter of the area to be repaired shall be cut with a concrete saw to the specified depth. Transverse perimeter cuts are first made around the boundary of the repair down to about a quarter (1/4th) to a third (1/3rd) of the slab thickness (See **Fig. 9.1**). Separate full depth cuts are then made for removal of the slab. The concrete between the two cuts provides a buffer to prevent undercut spalling and allows chipping for exposing the steel dowel/tie bar reinforcement. Always cut toward the shoulder so that any shear forces developed from the compression of the slabs get concentrated and relieved in the paved shoulder portion. After removal of the slab through lift or break-and-remove method, the quality of DLC is inspected for any cracks, deterioration, settlement or damages. Necessary core tests may be conducted to validate functional existence of the DLC. If found unsatisfactory, the DLC should be cut & removed. Similarly checks shall continue for next layer until intercepted layer seems satisfactory.

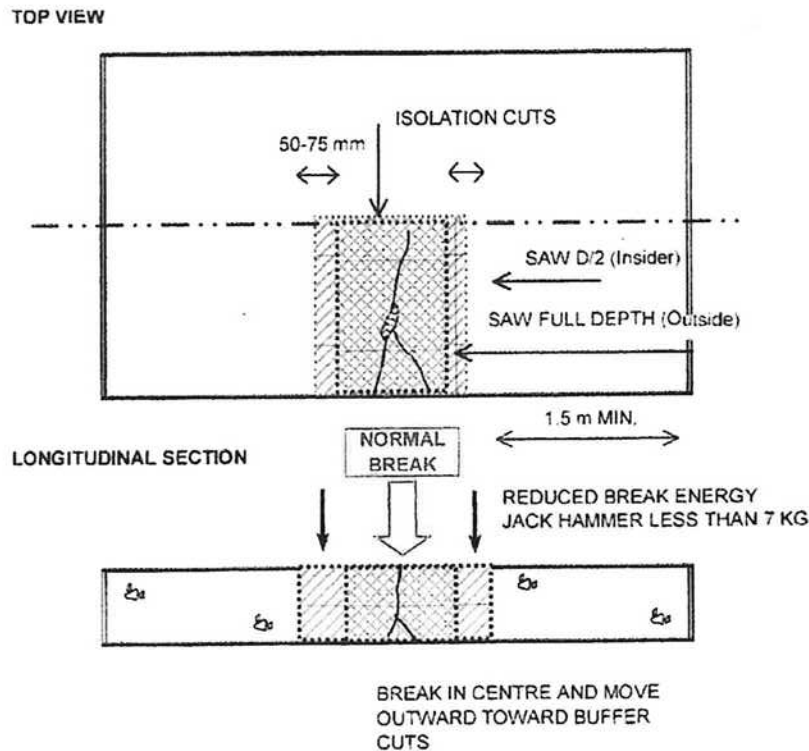


Fig. 9.1 Buffer Cuts for Protecting Repair Perimeters from Undercut Spalling

- (iv) The advantages of sawing patch boundaries include the following:
 - a) The saw leaves vertical edge faces
 - b) During breaking the patch area is isolated within the sawed boundaries and the risk of damage in the adjacent slab areas is therefore minimized. Full depth saw overcuts should end within this buffer area.
 - c) Spalling of adjacent slab areas is also minimized
 - d) Breaking, chipping and removing debris within the sawed boundary is usually easier and faster
- (v) The disadvantages of sawing patch boundaries include the following:
 - a) More workers are required than for other procedures
 - b) Water used to cool the saw-wheel saturates the repair area and drying time may delay the work
 - c) Saw polished vertical patch boundaries provide poor bonding. This is alleviated by manual chiselling or by means of light jackhammers or roughening by sand-blasting the polished sides.
- (vi) Holes are drilled for dowel bars or tie bars in the edge walls of the remaining slab portion (**Fig. 9.2**). Rather than single hand-held drills, it is better to provide enough space for using dowel-drilling rigs with wheels to properly control alignment and wandering. Both standard pneumatic or hydraulic percussion drills are acceptable. They drill a hole in about 30 seconds. Electric pneumatic rotary drills take three to four times longer. The hole shall be 2 mm bigger than bar diameter for epoxy anchor material or 6 mm bigger than the bar diameter for cement based anchor material.

- (vii) The dowel hole is cleaned carefully by means of a nozzle and compressed air. Prior to this operation ensure that the compressor is not blowing oil and moisture contaminated air by blowing into a piece of dry cloth.
- (viii) The epoxy anchoring material is fed to the back of the hole before inserting the dowel/tie bars. This ensures that the anchoring material will flow outward along the entire dowel/tie embedment length during insertion and decreases the likelihood of leaving voids between the dowel and concrete (**Fig. 9.3**).



Fig. 9.2 Drilling of Holes for Dowel Installation



Fig. 9.3 Epoxy Injection into Holes

- (ix) Reinforcement is fixed in top of the repair when the length to width ratio of the patch exceeds 1.5 so to control any cracking on account of the shape factor. (10 mm dia high yield deformed bar@ 200 mm c/c in both directions). The reinforcement shall be placed about 75 mm below the top surface.
- (x) 1:1 cement sand slurry with water/cement 0.4 - 0.62 is applied on the sides and bottom of the pit before pouring fresh concrete.
- (xi) Concrete is poured in the pit from ready mix or batch trucks, or site mixed for small jobs in small mixers. Evenly distribute and compact the mix by penetration of a vertical vibrator. Special care is important to compact concrete in the corners, along the patch perimeter and around the dowel bars.
- (xii) Strike off and finish the concrete surface with a vibrating screed or manual screed depending upon the size of work. Hand finishing should be minimum as it will leave undulations in the surface.
- (xiii) A wire brush/tined texture is applied to get surface texture to match the texture of the existing pavement.
- (xiv) Suitable curing conditions are provided immediately by means of a liquid membrane curing compound.
- (xv) Laboratory tests shall be performed in advance to determine the appropriate mix proportions and establish the time required to achieve the minimum compressive strength required to open to traffic. The minimum compressive strength of repairs before opening to traffic should not be less than 32 MPa .
- (xvi) The methods for placement and curing the concrete shall take into consideration the weather, seasonal and other environmental factors.
- (xvii) **Figs. 9.4 & 9.5** gives further details about the Full Depth Repair (FDR).



(a) Dowel Bars Placed Manually on Chairs



(b) Rusted Dowel Bars from Removed PQC

Fig. 9.4 Installation of Dowel Bars on Chair for Full Depth Repair

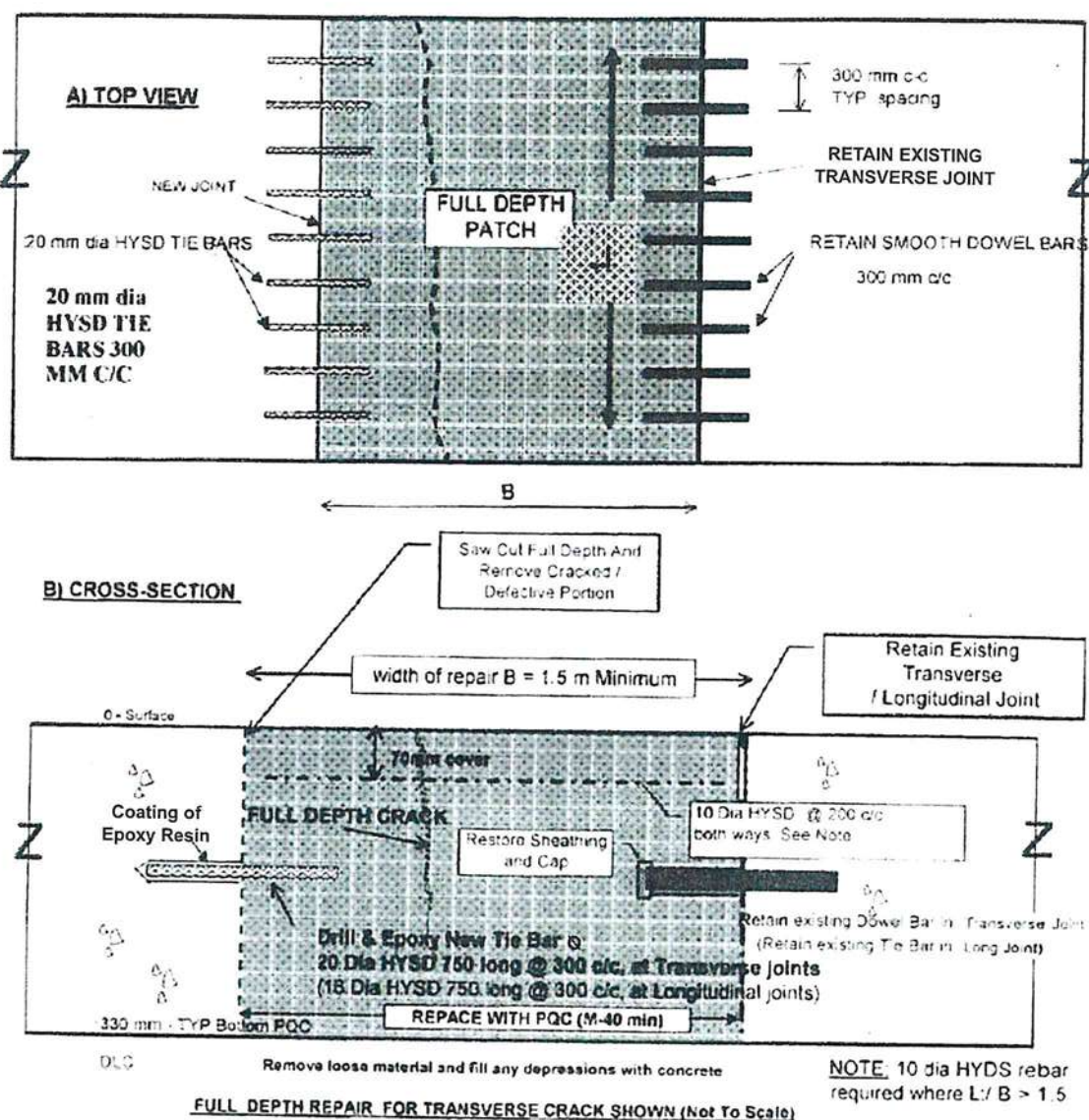


Fig. 9.5 Full Depth Repair of Cement Concrete Pavement

9.3 Replacement of a whole slab comprises of essentially the same process except that after removal of damaged slabs it is important to check the causes of damage that could be poor drainage or Jack of support. Before reconstruction the sub-drainage system and the sub-base shall be repaired as appropriate and the interface reinstated. Repair procedure for the replacement of a whole slab is otherwise the same as that of full depth repair described in this Chapter. New dowel and tie bars shall also be retrofitted, if required.

9.4 Whole slab replacement requires fixing tie bars along the longitudinal joint. Drill holes to suit 16 Dia deformed reinforcing bars with embedment length appropriate to the anchor material. Hand held drills are acceptable because alignment is not critical.

10 SLAB STABILISATION

10.1 General

Slab stabilization refers to the method for raising sunken slabs by pressure grouting under the slab after boring vertical holes for pressure injection of the slurry. It is also sometimes called undersealing or sub-sealing. It is most often performed at areas where pumping or loss of support has occurred. The most common materials are cement and fly-ash grouts or polyurethane mixture etc. selected according to the fluidity, durability and cost.

10.1.1 Several phenomenon like mud pumping and settlement cause voids under concrete pavements. Heavy axle loads induce the highest slab deflections near transverse joints and working cracks away from transverse joints. Deflections may cause erosion, consolidation, with the resultant loss of the sub-base or sub-grade support. Without support underneath the slab, load stresses in the concrete increase and may cause other problems, such as faulting, corner breaks, and cracking. The voids usually occur near cracks, joints, or along the pavement edge, and are often not more than 3 mm to 4 mm deep. The grout fills these voids beneath the concrete pavement slab or sub-base layer and displaces free water. Transverse joint faulting and presence of water at or near joints and cracks on the traffic lane or shoulder are good indications of pumping and voids. Corner breaks and shoulder drop off are further indicators of voids under the slabs.

10.1.2 Slab stabilization is intended to fill the voids beneath the slab. Slab stabilization requires an effective method for locating the voids. This may be done by the following evaluation methods, but each has its limitations.

- (i) Visual inspection: This method has several deficiencies especially when evaluating effectiveness of stabilization.
- (ii) Deflection measurement by FWD (Falling Weight Deflectometer).
- (iii) Ground Penetrating Radar (GPR).

10.1.3 The principle requirements in selection of materials are strength and ability to flow into or expand to fill the very small voids and water channels. The main advantage of polyurethane grouts are the tensile strength and fast cure time. But usually pozzolana-cement grouts are preferred due to availability and cost effectiveness.

10.1.4 A typical pozzolana cement grout uses one part cement to three parts flyash. Quantity of water is typically in the range of 1.5 to 3 parts by weight of mix. Tests shall be conducted thoroughly, i.e.: 1, 3 and 7 day compressive strength, flow cone times and initial set times. Engineers use the

flow cone during the concrete mix design process to determine the quantity of water required. The Contractor shall check the grout consistency twice each day using the flow cone (ASTM C 939).

10.2 Pressure Grouting

It comprises the following tasks:

- (i) The repair materials and procedure are selected.
- (ii) Holes are drilled for grout injection using pneumatic or hydraulic rotary percussion drill on a 1 m square grid over the whole area of voids to be filled under the slab; drill depth = slab thickness + 20 mm, drill vertical hole of dia 30 mm - 50 mm as appropriate to best suit the available equipment, distance to joints and cracks = 0.5 m to 1.0 m.
- (iii) Compressed air is blown to remove water etc under the slab for the grout injection. The work sequence should be across and along the slab going downwards crossfalls and longitudinal gradients.
- (iv) Grout is injected in each hole at a pressure of 0.35 N/mm² working in sequence across and along the slabs, until the void accept no more grout or grout flows up through an adjacent hole or the slab begins to rise. A short pressure surge up to 2.0 MPa may be necessary to clear debris from the grout hole for 2-3 seconds only.
- (v) For early and fast flow of grout and to minimize air beneath the PQC two holes are drilled, vacuum pump may be used by sucking air from second hole.
- (vi) Excess grout upon completion is removed from the pavement surface. If resin grout was used that cannot be removed the slab surface may be blinded with fine hard aggregate.
- (vii) Injection holes are cleaned and filled with cement or resin mortar.
- (viii) Traffic is opened only after the minimum appropriate curing time.

10.3 Vacuum Grouting

Vacuum grouting comprises of the following tasks:

- (i) Holes are drilled for grout injection on a 1 m square grid over the whole area of voids to be filled under the slab.
- (ii) The holes are temporarily plugged and the slab surface is swept to clean all debris.
- (iii) Vacuum channels are placed in position.
- (iv) Transparent flexible plastic sheet is placed over the area to be grouted on top of the vacuum channels.
- (v) The perimeter of the plastic sheet is sealed. The vacuum injection holes are sealed to prevent ingress of air.
- (vi) Vacuum is applied and any water from the void beneath the slab is drawn off (**Fig. 10.1**).
- (vii) With the vacuum applied puncture the plastic sheet at the injection holes and pour grout in each hole in the working sequence. The hole is plugged as soon as grout begins to be drawn up.
- (viii) Upon completion excess grout shall be removed from the pavement surface.

- (ix) Vacuum injection holes are cleaned and filled with cement or resin mortar.
- (ix) The traffic is opened after the minimum appropriate curing time.

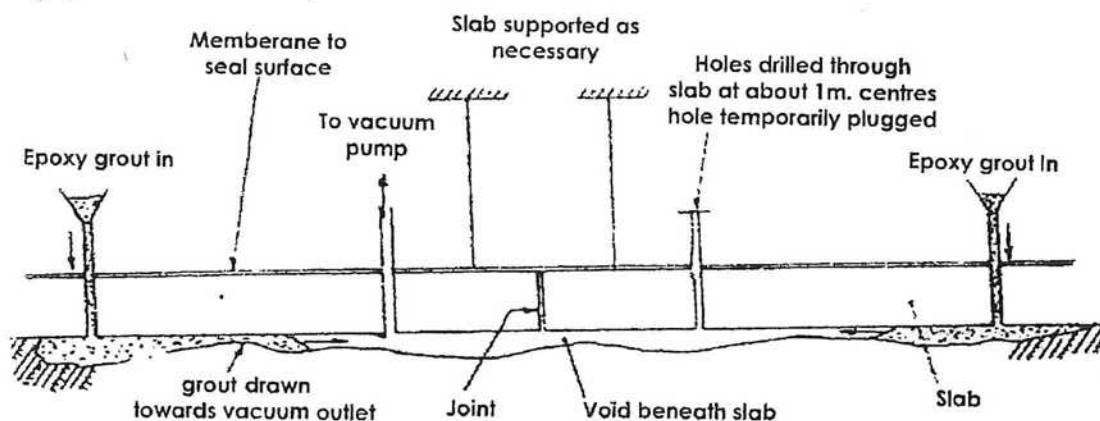


Fig. 10.1 Vacuum Grouting with Epoxy or other Repair Material

11 SPECIAL TECHNIQUES FOR REHABILITATION OF RIGID PAVEMENTS

11.1 Repair for Load Transfer Failure (Retrofit of Dowel Bars)

11.1.1 New dowel bars shall be placed at cracks where displacements occur and at joints if the existing bars are damaged (misaligned, bent or corroded dowels, dowel socketing or dowel slot widening). At least three bars in every wheel track at 300-375 mm spacing (**Figs. 11.1 & 11.2**) shall be installed as per procedure given below. For existing dowel bars, there can be two ways of retrofitting. If there are no cracks along the existing dowel bars, the retrofit slots can be cut out in the land space between the existing bars and new bars be installed. However, if the existing bars are corroded or surrounding concrete is cracked, the retrofit slot be cut out encompassing the damaged bar. This tantamount to replacement of dowels by retrofit. The spacing is 300-375 mm. This repair method re-establishes load transfer across the joint or crack, while at the same time allowing longitudinal movement. Poor load transfer may originate faulting, sub-base damage, corner breaks, or spalling.

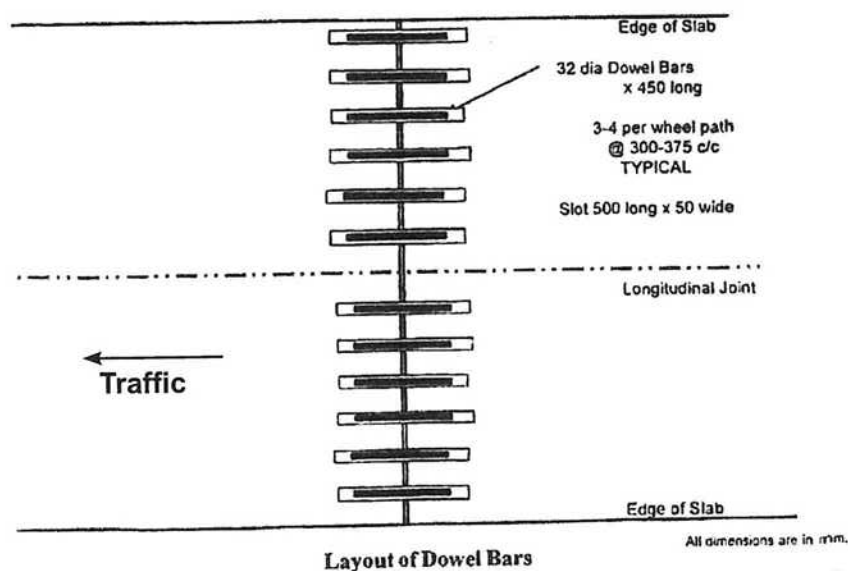


Fig. 11.1 Layout Plan of Retrofit Dowel Bars

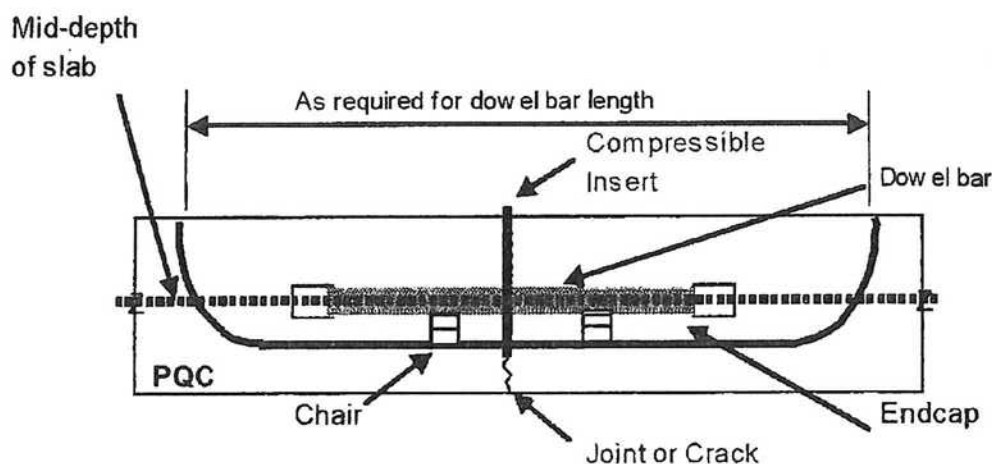


Fig. 11.2 Side View of Retrofit Dowel Bars

11.1.2 The work procedure for retro-fitting dowel bars consists of following steps:

- (i) The repair materials are selected.
- (ii) The slot to be cut is marked parallel to the centre line of the pavement with a length of about 800- 900 mm ensuring half-length on either side of crack/joint.
- (iii) Vertical holes (40 mm diameter) are drilled at the ends of the planned slot to such a depth that the dowel bar center line will be in the middle of the slab thickness.
- (iv) The slot sides are cut and the bottom sides are levelled between the holes drilled at each end. Diamond-saw slot cutting is the most reliable and proven method. Diamond-saw slot cutting machines can make multiple cuts to form the edges of three (one wheel path) or six (two wheel paths) slots. The saw operator aligns the head before the joint or crack then plunges into the concrete and advances across the joint or crack. The plunging and moving back and forth across the joint or crack creates a flat bottom at the required depth.

The jack hammer may be placed either at the end of the fin or downed along the bottom or along the side of the slot to break the fin. The tin may be removed easily in two or three big pieces. The fins can also be removed manually with the help of hammer and chisel. The small projections at the bottom of slot be broadly flattened with small jack hammer or manually with hand hammer and chisel. The slots are cut parallel to the center line of the pavement. The slots are 50 mm to 65 mm wide and slightly deeper than half the slab depth so as to ensure that dowel is at mid depth of slab. The outside wheel path dowel is between 300 mm to 375 mm from the pavement edge and the inside wheel path dowels shall be 450 mm to 600 mm inside the center line of the pavement. The spacing between the dowels may be between 300 mm to 375 mm center to center.

- (v) Joints and transverse cracks with a load transfer of less than 40% shall be retrofitted with dowels prior to diamond grinding. The total deflection of slabs shall also be checked to ensure that it is less than 0.8 mm. If the deflection is greater than 0.8 mm the slabs should be stabilised prior to diamond grinding.

Local spot grinding is not recommended and is otherwise going to be very expensive for just mobilising the machine.

- (vi) The slots/pits are cleaned carefully and dried out if moist. This is done by sand blasting followed by air blasting. The slot is checked by wiping a hand along the slot walls and bottom. Laitance or dust adhering to the hand would indicate that further cleaning is necessary.
- (vii) The crack or joint is caulked at the bottom and sides of the slot to keep patching material from entering the crack or joint and build bridges across the crack or joint.
- (viii) The dowel is covered with debonding agent such as form oil or grease to allow slide movement within the hardened patch. No oil or grease shall fall onto any of the slot surfaces because it would not allow the patching material to bond to the slot and could cause the patch to fail. Placing a sleeve over the dowel is not recommended because inherent looseness could cause the dowel to socket and fail.
- (ix) The dowel is prepared with non-metallic expansion end caps, a plastic foam or filler board joint reformer in the middle and non-metallic chairs. Retrofitting dowels are the same as those used in the pavement with a few modifications. Dowels mostly used are round mild steel bars not less than 450 mm long. Depending on the slab thickness, the dowel diameter is 32 mm to 36 mm. (Ref: IRC:58). Before applying form oil or grease the dowels should be epoxy coated over the entire surface including the ends to prevent corrosion and joint lock-up.
- (x) A resin coat is applied to the slot walls and a resin mortar layer to the slot bottom before placing the dowel horizontally, if the patching mix is resin mortar.
- (xi) The dowels in the slots are inserted so that the chair legs are in the saw-cut kerfs at the bottom of the slot. In this position, the dowel will be aligned in the pavement middle line. Parallel to the pavement surface. The joint reformer should be over the joint or crack with half-length dowel on each side. The legs and sides of the chairs should be snug against the slot walls to keep the dowel from moving during placement of the patch material.
- (xii) The slot is filled with resin or fast track concrete mortar which attains minimum compressive strength of 10 MPa within 3 hours. Compact with a spud vibrator around the dowel without hitting it.

The patch mix shall have all the properties similar to concrete and have little or no shrinkage. It shall set and develop strength quickly to allow traffic as soon as possible (32 MPa minimum).

- | | |
|-------------------------|---|
| • Compressive Strength | 40 MPa (minimum) after 28 days (IS:516) |
| • Bond (Shear) Strength | 7 MPa (minimum) after 28 days |

- (xiii) A curing compound is applied.

- (xiv) The road can be opened to traffic when the patch material has gained strength of at least 32 MPa. The pavement is then finished with diamond grinding.

The Retrofitting of dowel bars is illustrated in **Fig. 11.3**.

11.1.3 Retrofit of tie-bars

The method of placing retrofit tie bars across longitudinal cracks is similar to the above, except spacing shall be 450-600 mm depending on thickness of slab. Procedure is similar to slot stitching illustrated in Fig. 7.4.



(a) Grooving along the Transverse Crack



(b) Placing Dowels Slots and Filling the Slots

Fig. 11.3 Retrofitting of Dowel Bars at Transverse Crack

11.2 Slab Lifting or Jacking

11.2.1 This repair method consists of raising sunken slabs to the level of adjacent slabs by lifting or pressure grouting beneath the panel.

11.2.2 The first method comprises the following tasks:

- (i) A full depth saw cut is made along longitudinal joint(s) to separate the slabs to be raised from the adjacent panels
- (ii) Holes suitably sized are drilled lifting into the slab at positions to fit the lifting frame
- (iii) The hydraulically operated lifting frames are positioned transversely with lifting bolts centered over the lifting holes
- (iv) Threaded female sleeves are fixed into the lifting holes with resin grout or mortar
- (v) The lifting bolts are screwed into the threaded sleeves
- (vi) A level reference datum across the slab to be raised is established.
- (vii) The slab is raised to the required level slowly by operating hydraulic jacks at each corner of the lifting frame
- (viii) The void is filled beneath the slab with fast hardening cement grout
- (ix) Traffic is opened only after the minimum required curing period and adequate strength.

11.3 Restoration of Evenness and Skid Resistance (Diamond Grinding)

11.3.1 Removing of bumps and re-profiling of surface of concrete pavement by means of diamond grinding improves the surface evenness and decreases severity of impact from

dynamic load of vehicles. Presence of bumps and unevenness in pavement causes increased tensile stress in the pavement and reduces its life.

11.3.2 Diamond grinding can also be used to smooth out roughness from slab surface, to even out curled or warped slabs and remove patching unevenness. It removes a thin layer of concrete from the surface of the pavement.

11.3.3 PQC Grinding is required when there is severe surface deterioration causing problem to end user like FOD problem in runways, removal of bumps or flattening of profile due to construction error causing FRL mismatch in adjacent panels casted, on surfaces that are exposed to snow and are susceptible to treatment with de-icing chemicals, exposed aggregate surface or surface blemishes that need to be removed to ensure longer life of the pavement etc. Grinding should be followed by applying a layer of siloxane based solution for best results.

11.3.4 Numerous forms of machines are manufactured to carry out diamond grinding as per requirement of the client. A typical machine generally grinds from 3 mm up to 5 mm. The localized bumps or the damage surface is to be measured with straight edge & the area to be ground is marked. The machine is operated in end to end pass on the pavement (parallel to transverse joint preferably). Grinded surface resembles typical Indian mosaic flooring with micro texture serrations exposing fresh layer of concrete.

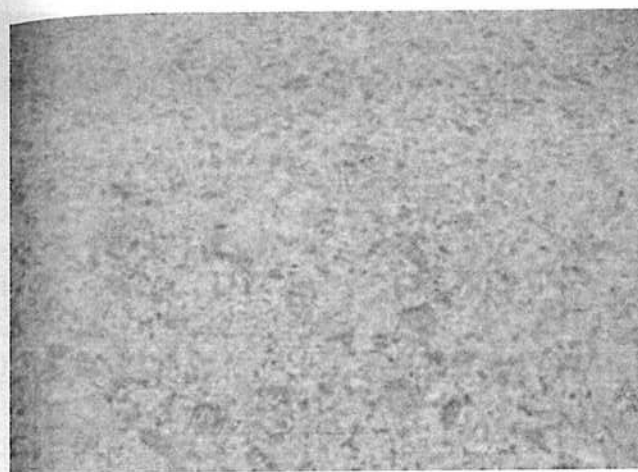
11.3.5 Before commencing grinding operations all forms of loose concrete in corners, potholes, pop outs etc should be patched with elastomeric cement to give best results. Special care is to be taken when machine is moving across joints to ensure the sealant is not damaged in grinding operation. It is best to reseal post grinding. After grinding the slurry should be cleaned using water jet & section should be inspected using a straight edge.

11.3.6 Although diamond grinding does reduce the thickness of the pavement, by making the surface even and by reducing tensile stress in slab it adds to the overall life of the pavement. Depending of the equipment used for diamond grinding, if the texture on the slab lacks required level of friction, the slab may have to be subjected to diamond grooving after completion of diamond grinding. **Table 11.1** may be referred for factors limiting diamond grinding.

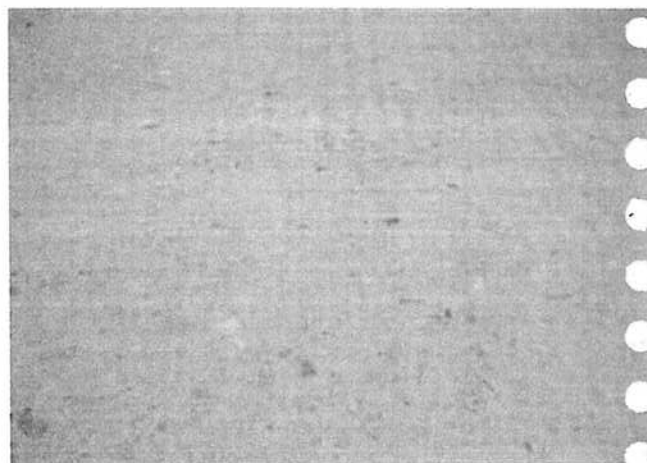
Table 11.1 Limiting Values after Diamond Grinding
(Published by permission of ACPA Copyright, 2008)

Sr. No.	Roughness Index	AVERAGE DAILY TRAFFIC (ADT)		
		ADT > 10,000	10,000 > ADT > 3,000	ADT < 3000
1.	IRI (m/km)*	2.5	3.0	3.5
2.	BI (mm/km)	1800	2200	2560
3.	General Application	Expressways, Airport Runways	National and State Highways	Other Important Roads

Fig. 11.4 shows the concrete surface before and after diamond grinding.



(a) Before Grinding



(b) After Grinding

Fig. 11.4 Concrete Pavement Surface Before and After Diamond Grinding

11.4 Diamond Grooving

It is a specialized technique used to restore skid resistance at the surface of concrete pavement and to reduce wet weather accidents, improve traction and prevent hydroplaning. PQC Grooving is required to prevent formation of water film between tyre of vehicle and the pavement leading to loss of traction and wet weather accidents, in areas where reduction in stopping distance is required by increasing traction, in areas where rectification of lost texture is required due to accidental occurrence of rain during PQC laying, and to increase pavement service life by adding more friction capabilities the texture depth (to be checked every 3 to 5 years).

11.4.1 Grooving generally provides the best treatment against aqua planning on high speed expressways. It is like grinding cut with diamond impregnated blades or cylinder rings. The grooves are usually cut in a transverse direction, are 3 mm to 5 mm deep & 3 mm to 4 mm wide with a distance of 10 mm to 40 mm between lines. Grooving is intended to help water expulse or under tyres. This treatment shall be considered on pavements that have exhibited a significant number of wet weather accidents (usually on curves or at junctions).

11.4.2 The labor/head width can be substantially larger considering the larger spacing between the blades. Longitudinal grooves produce less noise than transverse grooves, however they help raising water spray trails of splash. In Indian conditions with high rainfall and slow moving vehicles transverse grooves should be preferred.

11.4.3 Surface grooving comprises the following tasks:

- (i) All joints shall be effectively sealed against ingress of sawing slurry
- (ii) Sawing slurry is prevented from entering surface water drains
- (iii) The surface is textured by sawing randomly spaced grooves 3 mm wide by a least 4 mm deep
- (iv) Deposits of slurry are flushed and removed from the pavement surface

11.4.4 Grooves shall not be cut within 150 mm of the outside edge of the slab and longitudinal joints.

11.4.5 *Determination of requirement of retexturing by measurement of mean texture depth.*

Skid resistance and noise of roads highly depend on the characteristics of pavement Texture. Therefore, the estimation of texture characteristics may give useful information for the skid resistance and noise of road. As an indicator, MTD (Mean Texture Depth) is generally measured by the Sand Patch Test (SPT). Even though the SPT can be simply conducted with very low cost, it has some disadvantages including time-consuming and traffic interruption. The basic principle of quantitatively measuring the texture depth of pavement surface is by calculating the volume of the apertures between the aggregates through MTD method, commonly using Sand Patch Test. Sand Patch Test is a method of calculating MTD by evenly filling the apertures on the pavement surface with 25 cm^3 of dry natural sand with a rounded particle shape passing 300 micron and retained on 150 micron IS sieve. The diameter of the patch shall be measured to the nearest 5 mm. The mean texture depth is calculated as $31000/D^2$ mm, where D is the diameter of the patch in mm.

Five individual measurements of the texture depth shall be taken at least 2 m apart anywhere along a diagonal line across a lane width between points 50 m apart along the pavement. No measurement shall be taken within 300 mm of the longitudinal edges of a concrete slab constructed in one pass. In case the MTD value is below the standard value of 1.25 mm the surface needs to be re-textured.

Fig. 11.5 shows the grooving of concrete pavement surface.



Fig. 11.5 Diamond Grooving of Concrete Pavement Surface

11.5 Milling Procedure

11.5.1 Milling is only recommended as a procedure for the preparation/treatment of a concrete surface for receiving a bonded overlay. Standard milling machines with 300 mm or 450 mm wide cutting heads have proven efficient and economical particularly when used for large areas, such as full lane-width repairs.

11.5.2 The milling operation results in a rounded pit. The borders shall be made vertical by sawing or jack hammering or chiselling.

11.5.3 The advantages of the mill procedure include the following:

- (i) It is efficient and economic for large areas
- (ii) It leaves a rough surface that promotes bonding of the patch

11.5.4 *This procedure has the following disadvantages:*

- (i) For repair areas shorter than 0.09 m², the smallest milling head results in a patch larger than needed
- (ii) Milling may cause spalling of border edges
- (iii) The pit edges perpendicular to the milling operation (and traffic direction) are rounded. These edges shall be made vertical by chiselling or cutting

11.5.5 When cold-milling is used, a secondary cleaning should follow to ensure the removal of dust and particulate material from the milling operation. Secondary cleaning can be done with sand blasting, water blasting, sweeping or air blowing equipment. This should be accomplished if immediately prior to applying the bonding grout.

11.5.6 Shot blasting is performed by a self contained mechanical unit that will cause no dust or particulate problems. The machine is capable of removing all surface contaminants, except some difficulty is encountered in removal of asphalt concrete or asphalt cement. The machine will throw abrasive metal shot at the surface in a contained cleaning head. The particulate matter and dust created by the operation is also picked up and discharged. The average depth of removal for this equipment is about 3 mm. Care shall be taken when using shot blasting equipment, that the shot does not penetrate the joint. It is recommended that a backer rod be installed in all open transverse joint grooves prior to the shot blasting operation to avoid penetration of shot that could eventually cause compression failures. Depending on the efficiency of the vacuum attachment available on the equipment, secondary cleaning may not be necessary after this procedure, but it is highly recommended.

11.6 Concrete Overlays

11.6.1 General

If the existing rigid pavement is structurally weak based on the prevailing traffic or the wearing surface needs improvements in riding quality an overlay over rigid pavements is generally laid as per IRC:SP:17 "Recommendations for Concrete Overlays on Concrete Pavements".

There are the following main types of overlay:

- (i) Partially bonded rigid overlay over cement concrete pavement
- (ii) Unbonded rigid overlay over cement concrete pavement
- (iii) Fully bonded rigid overlay over cement concrete pavement
- (iv) Cement concrete overlay over bituminous pavements, as per IRC:SP:76

Family of overlays is given in **Fig. 11.6**.

11.6.2 Partially bonded overlay

For partially bonded overlay, the concrete pavement should be cleaned of any loose or extraneous matter, given a detergent wash @ 1 kg/10 sqm. Along with scrubbing with wire brush to remove oily and greasy materials. Subsequently the whole surface is flushed with water to remove all traces of the solution and other dust particles. Partially bonded overlay over rigid pavement is designed as per the formula given below, with matching the joints in top PQC with those in existing PQC layer:

$$h_o = (h_m^{1.4} - C h_e^{1.4})^{1/1.4} \quad \text{Eq. 11.1}$$

where, h_o = thickness of concrete overlay, cm

h_m = thickness required for monolithic slab needed for the projected traffic as per IRC:58, cm

h_e = thickness of existing concrete pavement, cm

C = pavement condition factor as per **Table 11.2**

Typical Application of Partially Bonded Overlays are for the treatment of slightly cracked concrete pavement.

Table 11.2 Pavement Condition Factor as per Different Categories of Distress

S No.	Length of Crack in m per 10 sq.m.	Category	Condition Factor, C
1.	0 - 1	Sound	1.00
2.	Exceeding 1-2.5	Slightly cracked	1.00
3.	Exceeding 2.5- 5.5	Fairly cracked	0.75
4.	Exceeding 5.5 -8.5	Moderately cracked	0.55
5.	Exceeding 8.5 - 12.0	Badly cracked	0.35
6.	Exceeding 12.0	Very badly cracked	0.25

* Further guidance may be taken from IRC:SP:17

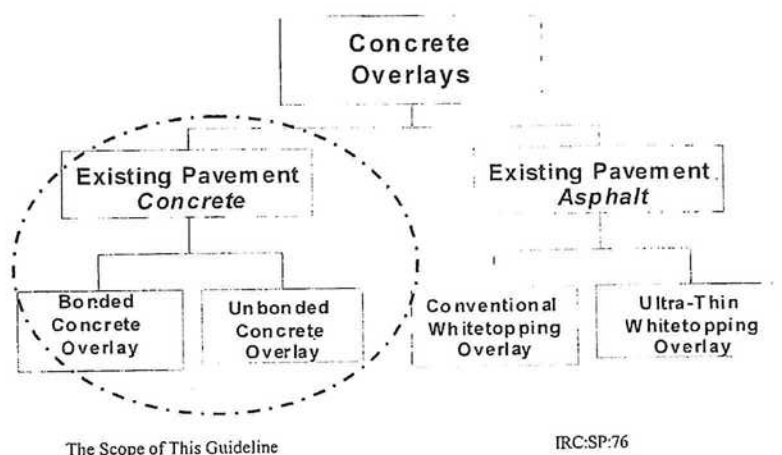


Fig. 11.6. Family of Overlay Concrete

11.6.3 Un-bonded overlay

Generally consists of a thick concrete layer (125 mm or greater on top of an existing concrete pavement. A separation interlayer is provided to separate the new and existing concrete surface as per Fig. 11.7. At least 100 mm bituminous separation layer of bituminous macadam or (levelin course grading) may be adopted.

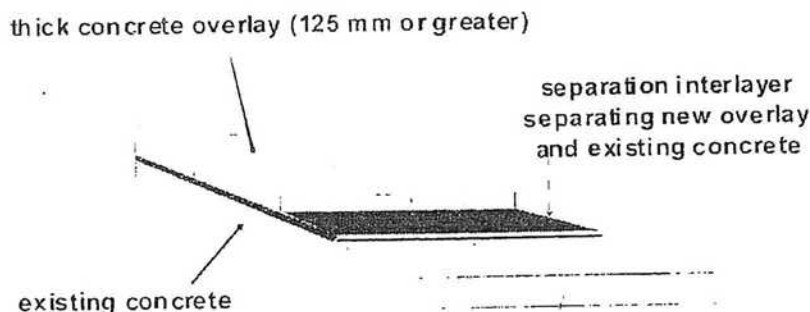


Fig. 11.7 Unbonded Concrete Overlay

The optimum thickness separation interlayer prevents distress reflecting into the overlay as shown in Fig 11.8

Typical applications of unbonded Concrete Overlays are:

- For treatment of the pavements having little or no structural life remaining
- Pavements displaying extensive and severe durability distress
- Medium to heavily trafficked roads
- Treatment for pavements over very weak or wet subgrade

For an unbonded overlay, rocking slabs shall be rectified, exposed sub base properly compacted and gap may be filled with bituminous macadam having 2.5% - 3% binder sealed properly with bituminous materials

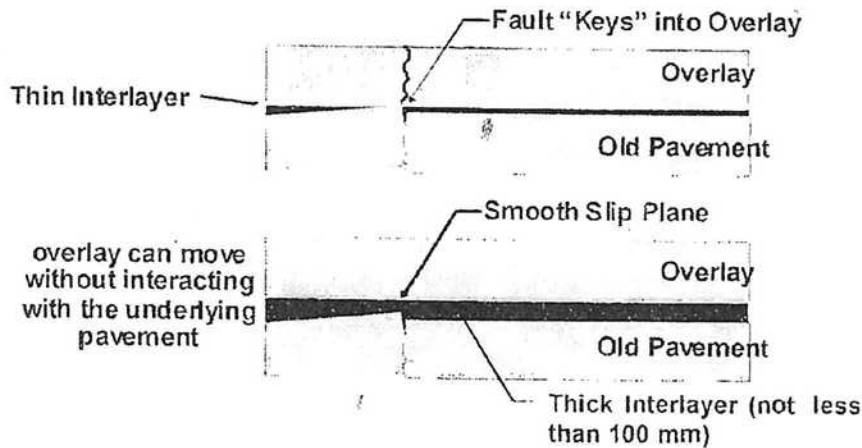


Fig. 11.8 Effects of Separation Inter Layer Thickness

An un-bonded overlay over rigid pavement is designed as per the formula is given below:

$$h_o = (h_m^2 - C h_e^2)^{1/2} \quad \text{Eq. 11.2}$$

where, h_o = thickness of concrete overlay, cm

h_m = thickness required for monolithic slab needed for the projected traffic as per IRC:58, cm

h_e = thickness of existing concrete pavement, cm

C = pavement condition factor as per **Table 11.2**

11.6.4 Fully bonded overlay

Generally consists of a concrete layer (100 mm to 150 mm) on top of an existing concrete surface. Specific steps are taken to bond the new concrete overlay to existing concrete as shown in **Fig. 11.7**.

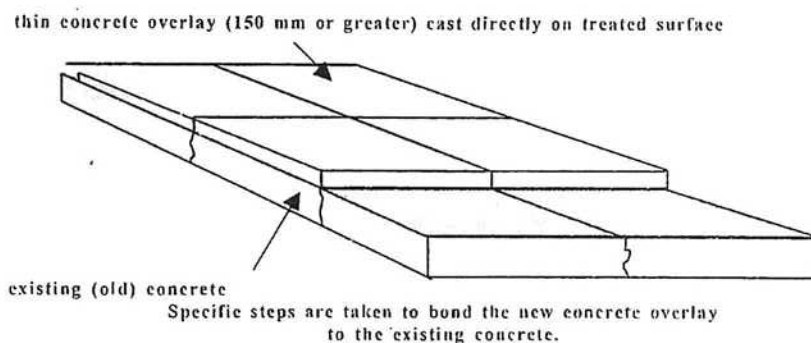


Fig. 11.7. Bonded Concrete Overlay

Bonded overlays are suitable over sound uncracked concrete pavement. Typical applications for a bonded overlay are:

- to correct surface problems relating to wear or loss of skid resistance
- to repair damage caused by chemical spills
- to improve load carrying capacity

Bonded overlays need to be used with great caution as they are not suitable over moderately or badly distressed pavements or over concrete with reactive aggregate problems or over poor subgrade.

All treatments for the preparation of the existing slabs as specified for partially bonded overlay are also applicable to fully bonded overlays. Besides this, all bond-preventing materials such as joint sealing compound, bituminous materials used for repair, paint marking, greasy and oily marks etc. should be meticulously removed. Where ever necessary, light chiseling to scarify the surface for effective bond and to remove loose materials at the surface may be done. The surface is initially flushed with water to remove all traces of spilled oil or bitumen driplings. On the saturated surface dry slabs, bonded rigid overlay should be laid immediately after applying a thin layer (about 1 mm) of 1:1 cement sand paste/slurry as bonding medium. Shot blasting the existing surface without using grouts reportedly gives the best results (Ref: Research University of Texas, USA). For more details separate guidelines be referred. It has been the experience that fully bonded overlays with passage of time end up with partial bond. Fully bonded overlay may be designed as per the formula given below:

$$h_o = (h_m - h_e) \quad (\text{Eq. 11.3*})$$

* Further guidance may be taken from IRC:SP:17

11.6.5 Additional precautions for concrete overlays

- (1) In high rainfall areas, particularly where the drainage is not satisfactory and/or on pavement carrying very heavy traffic of more than 1500 commercial vehicles per day. Mild steel reinforcement at the rate of 3 kg/sq.m should be provided in fully bonded and partially bonded overlays. Mild steel reinforcement mesh @ 3-6 kg/sq.m may also be provided in overlay across cracks in existing pavement. This reinforcement will be provided 60-75 mm below the top surface of overlay.
- (2) Mild steel shear pegs, if required, may be provided. A mild steel bar mesh, extending 500 mm on either side of the crack may also be embedded at mid depth in the concrete overlay. Joints in the overlay may be matched with those in the existing pavement both in type and location. Extra care may be taken to ensure that all edges and corners of the concrete slabs are fully coated with the cement slurry. This is particularly important as these regions are more susceptible to warping as well as initial differential drying shrinkage stresses and failure of bond in bonded concrete.
- (3) Efforts shall be made to minimize evaporation of water from the top surface by misting/fogging after 2 to 3 hours of laying concrete slabs and also by providing tentage at lower height with one end closed for avoiding wind tunnel effect to minimize plastic shrinkage. Addition of 0.2% fibres reduces the width of cracks if any, in case of concrete overlays. Casting of slabs from 1 am to 4 am in the early morning, may develop shrinkage cracks due to high warping stresses, if proper precaution regarding the covering of the PQC slabs with proper arrangements are not taken. These cracks which are noticed after 24 hours of laying slabs, shall be immediately filled with dry silica fume powder, fly ash and cement using

small quantity of water by application with brush. This type of treatment may be used for cracks of width less than 6 mm. These pavements after repair shall be covered with wet jute sheet (with minimum water).

11.7 Rehabilitation of Soft Earthen Shoulders

11.7.1 Shoulders should provide lateral support to the edges of the pavement, be of sufficient width and strength to support the parking of heavy vehicles under all weather conditions, shed off water, be durable and protect the lateral sub-drainage to the pavement below. Soft soil shoulders cannot comply with such requirements.

11.7.2 However on many of the National and State highway projects the earthen shoulders are constructed using fine soils which comply with the specifications for sub-grade but are easily eroded and worn away by heavy vehicles parking. The protection of lower side shoulder of super elevated portion requires special treatment or stabilization to withstand the cumulative run-off from both carriageways.

11.7.3 A report recommending the turfing or upgrading of the soft earthen shoulders is provided in **Appendix D** for the information of designers and maintenance engineers. Three options are given: turfing, using a trafficable soil gravel mixture and brick on edge.

12 REPAIR MATERIALS

12.1 General

12.1.1 Repair materials should have short setting times and develop strength fast enough to allow reopening of the lanes to traffic. In high traffic corridors the sections to be repaired can only be closed to traffic for a few hours. Lane closure of 6 to 24 hours is considered optimum. Portland Cement Concrete modified with chemical admixtures or polymers used in these applications is expected to become strong enough to carry traffic within 6 to 24 hours after placement. Rigorous requirements for mix design and strength are stipulated for EOT concrete applications. The uses of such concretes are bound to increase in future because with increasing traffic levels, only limited duration lane closure for repair is possible. This type of high early strength concrete is just emerging but durability related issues of such concretes are not & fully settled. A more cautious approach is recommended to be followed in India.

Para 12.3 of the guidelines briefly gives some details for such fast track concretes. Specialist literature like NCHRP report 540 "Guidelines for Early-Opening- to Traffic Portland Cement Concrete for Pavement Rehabilitation" which may be referred to, if interested.

12.1.2 *Repair materials may be classified under Three General Types:*

- a) Cementitious - Generally comprising of a Portland cement, gypsum or magnesium phosphate specially formulated to provide opening times of 2 - 8 hours or 20 - 24 hours (Ref: NCHRP Report 540).
- b) Polymer based - Generally comprising of an epoxy, methyl methacrylate, polyester-styrene or polyurethane based resin mixed with aggregates and a catalyst (hardener) formulated to provide opening times 6-8 hours.

- c) Bituminous - Comprising of a bituminous binder and aggregate mix, these materials are generally considered for making a temporary patch only.

12.1.3 The polymer based resins are preferably used for small areas and volumes of repair. An exception is patching of dowel slots where cement mortar is preferred to match the thermal properties of the surrounding concrete. The rapid setting cement based materials are used for larger areas and volumes to minimize differential thermal behavior and to minimize costs.

12.1.4 The minimum cube compressive strength to allow traffic is 32 MPa.

Note: It is necessary to remind that the several publications by FWHA and ACPA (USA) mentioned in **Appendix-A** report compressive strengths according to ASTM C 39 which tests cylinders (150 mm dia x 300 mm) long whereas in India the standard method for determining and reporting the compressive strength (IS:516) uses cubes (150 mm). The target cube compressive strength = cylinder Compressive strength/0.80 .

12.1.5 The repair materials shall be designed and tested in the laboratory and tested on the road so to conform to the manufacturers specifications.

12.1.6 The **Table 12.1** gives a guide to the selection of suitable patching material according to the size and depth of patch contemplated.

Table 12.1 Guidelines for Selection of Type of Product for Repair of Common Defects in Concrete Pavement

Sl. No	Type of Defect	Extent of Damage		Type of Product Recommended for Trial
		Maximum Surface Area	Minimum Depth	
1	a) Full Depth Repair b) Partial Depth repair	All All	Full Depth >100 mm	Conventional Cement Concrete modified with additives or polymers
2	Small Popouts	< 0.12m ²	30 mm	Epoxy Mortar (1:3)
3	Spalled Joints, Scaling	< 0.12m ² , Longest Dimension not Exceeding 600 mm	65 mm	Epoxy Mortar (1:3)
			75 mm	Epoxy Concrete (1:8)
4	Large Spalled Areas, Scaling	> 0.12 m ² , or Longest Dimension Exceeding 600 mm	30 mm	Elastomeric Concrete
		> 0.5 m ²	100 mm	Polymer Modified Cementitious Concrete

Sl. No	Type of Defect	Extent of Damage		Type of Product Recommended for Trial
		Maximum Surface Area	Minimum Depth	
5	Corner Breaks	< 0.12 m ²	30 mm	Epoxy Mortar
		> 0.12 m ²	65 mm	Elastomeric Concrete/Epoxy Mortar

12.2 Cement Mortars for Patching

12.2.1 The cement patch mixes often use IS:269 type Portland cement and also proprietary cementitious material that gain strength very quickly. To decrease the water-cement ratio a water reducing admixture may be required for 43/53 Grade Cement. In addition with accelerators to shorten the concrete setting time and aluminium powder to reduce shrinkage may be used.

12.2.2 The **Table 12.2** shows information on rapid-setting hydraulic binders or cementitious materials that are currently used for patching concrete pavements. Such binders often contain chloride based accelerators that may cause corrosion of dowel bars. Some polymer modified cement concrete mixes may reach a compressive strength of about 28 MPa within time as given in the **Table 12.2**.

Table 12.2 Typical Time to Achieve Compressive Strength 28 MPa

S. No	Material Category	Hours
1	Certain gypsum and magnesium Phosphate based cements	2-4
2	Sulfo-aluminate cements	2-4
3	Polymer modified methacrylate	2-4
4	Polymer urethane	1-2
5	43 Grade (IS:8112) or 53 Grade (IS: 12269) = cement chloride based accelerating admixture	4-6
6	43 Grade (IS:8112) or 53 Grade (IS: 12269) = cement with high range water reducing admixture	12-24

12.2.3 Some of the rapid-setting hydraulic binders are proprietary materials and in this case careful attention should be paid to manufacturers specifications. They should also be selected to match the climatic conditions that are expected during the repair work.

12.3 Fast-Track Concrete for Large Patching

12.3.1 Fast-track concrete or high early strength concrete is essential for full-depth/partial depth patching when early opening to traffic is required.

12.3.2 High early compressive strength concrete (20 - 25 MPa in 24 hours) is usually obtained using Grade 43 or 53 high-early strength cement, high cement content (350-450 kg/m³) lower water-cement ratios (0.3 to 0.35 by weight), well graded aggregates, and chemical accelerators. Super-plasticisers are also used to make the concrete mixture more workable during placement.

Fly ash, silica fume and ground granulated blast furnace slag are sometimes used in the mix to partially replace some of the Grade 43 or 53 cement. In some ready to use proprietary items polymers are also used.

12.3.3 Aggregate gradation uniformity will improve concrete strength, workability, and long term durability. The coarse and fine aggregate grading should be chosen to minimise voids in the matrix.

12.3.4 Calcium chloride (CaCl_2) should not be added as an accelerator under any circumstances.

12.3.5 Insulating blankets (or other insulation measures) can also be used in the first 24 hours to help strength gain by retaining the heat of hydration. Caution shall be taken, though, to avoid thermal shock when the blankets are taken off. Thermal shock may cause premature cracking of the concrete.

12.4 Elastomeric Concrete for Patching

12.4.1 Elastomeric concrete is a polyurethane based material designed to develop early high strength and easy bonding to a variety of materials. It comprises of a modified binder, fine aggregate and glass fiber. It hardens very quickly. It is relatively more expensive than normal epoxy mortar formulations but offers saving in the depth of the patch. Refer **Table 12.3**.

Table 12.3 Physical and Performance Properties of Elastomeric Concrete

Property	Minimum Requirement	ASTM Test Method
BINDER ONLY		
Gel time, minutes	5 minimum	
Tensile Strength, (MPa)	10 minimum	D 638
Elongation at break, %	200 min	D 638
Hardness Type D durometer, points	90 +/- 3	D 2240
COMPLETE BINDER-AGGREGATE MIXTURE		
Tensile strength, (MPa)	4.1	D 412 (mod)
Elongation at break (Ultimate), %	25 min	D 412 (mod)
Hardness Type D durometer, points	50 Shore D max	D 2240
Compression defection properties - stress (MPa), 5% deflection - resilience, 5% deflection	5.5 min/8.7 max 70 min	D 695 D 695 (mod)
Impact ball drop @ 29°, no cracking (Joule)	> 13.5	D 3029 (mod)
Adhesion to concrete (MPa)		
Dry Bond Wet Bond	2.4 minimum 1.4 minimum	

12.5 Resin Mortars for Patching

12.5.1 Commonly used resin binders are epoxy, poly urethane and methacrylate polymers. Resin binders should be selected for the climatic conditions that are expected during application work.

12.5.2 The various components of resin system must be kept in tightly closed containers. Smoking may not be allowed in the vicinity of the resins. After expiry of shelf-life, material shall not be used without rechecking its quality through laboratory tests. The following handling practice for resin materials and mixes is required:

- Working in a well-ventilated area (in case of laboratory tests)
- Storing the resin materials below eye level
- Using disposable containers, equipment and gloves, wherever feasible
- Using safety goggles when handling resin compounds
- Temperature of mix shall not be more than 60°C.

12.5.3 There is no solvent material for removing set resin-formulations. However unset/partial set resin from containers may be cleaned by:

- Mixture of equal proportions of ethyl alcohol and benzene
- Mixture of equal proportions of ethyl alcohol and toluene
- Toluene
- Benzene
- Ethyl alcohol
- Local soap/detergent

12.5.4 In addition to these guidelines, manufacturers recommendations for mixing, patching and curing should be strictly followed.

12.5.5 Fine or coarse aggregates depending on the application may be used in the epoxy resin formulation. The grading of fine aggregate, which is mainly used for repair is given in **Table 12.4**. Size of coarse aggregate is maximum 20 mm. Fine sand passing 1.18 mm sieve of FM 1.0 is used.

Table 12.4 Recommended Grading or Sand for Resin-Sand Mortars

Sr. No.	Sieve Size	Fine Sand % Passine	Medium Sand % Passing
1	4.76 mm	100	100
2	2.36 mm	100	100
3	1.18 mm	100	100
4	600 micron	95-100	50-60
5	300 micron	90-100	20-30
6	150 micron	5-20	20-30

Note: For better skid resistance hard silica, crushed stone, alumina, silicon carbide, slag etc 2 mm to 600 micron size may be used.

12.5.6 In epoxy formulations with tertiary amine as hardener, the quantity of the tertiary amine is limited between 4 gm - 10 gm per 100 gm epoxy resin for temperature range 40°C to 10°C. In resin mortars, generally one part by weight of resin formulation is mixed with 3-5 parts by weight of medium to fine sand. In case of epoxy resin concrete using larger maximum size of aggregate, the proportion of aggregate may be as high as eight (8) parts to one (1) part of resin formulation by weight.

12.5.7 The quantity to be mixed at a time should normally not exceed 2 kg because of the short pot life of the resins. The cement concrete temperature may be at least 15°C and preferably about 25°C, prior to application of the synthetic resin. Under cool weather conditions, electric heaters, for lighting 1000 Watt electric bulbs may be used in such a manner that the surface temperature stays below 40°C during the hardening period.

12.5.8 In general the compound is not heated beyond 60°C or cooled below 15°C. After applying the first tack coat on the bottom as well as sides of the prepared pit groove, the sides of the pit groove are given a second coat of resin formulation. Special care is required along the edges and at corners which are more prone to be left uncoated. For small sized work, a 20 mm hair brush may be used. Before the tack coat loses its tackiness, resin-sand mortar or concrete, depending on the depth of the patch, is placed in the grooved recess with the help of a trowel. For patches thicker than 20 mm, the sand is combined with a coarse aggregate having maximum size not greater than one-third the thickness of the patch. If the patch is deeper than 50 mm, it is built up in two or more layers to reduce heat build up and subsequent thermal contraction. Full compaction is ensured by rodding. A light layer of the dry sand should be spread over the finished patch. After application, the resin patch is kept at a temperature of 30°C - 40°C to accelerate curing by infrared lamps.

12.5.9 The use of polyester resins as bonding media between old and new concrete is generally ruled out on account of their high susceptibility to moisture. **Table 12.5** gives the typical formulations and properties.

12.6 Bituminous Materials for Patching

12.6.1 The use of bituminous mixes is very exceptional. Experience with bituminous binders for patching concrete slabs is not satisfactory and they are generally not recommended except for use as a temporary patch in emergency conditions when other more suitable materials are not available at site.

12.7 Joint Sealants and Backer Rods

12.7.1 The following section shall also be read in conjunction with Chapter 6.

12.7.2 Joint sealants can be divided into two broad categories:

- (i) Liquid (Field moulded) sealants which are poured or gunned into the joint
- (ii) Preformed factory moulded seals which are compressed into the fresh concrete or hardened joint

Table 12.5 Typical Values of Different Properties of Resin Formulations and Mortar

S. No.	Property	Typical Value
(a) EPOXY RESIN FORMULATION		
1	Coefficient of thermal expansion, 10-6 cm/°C	23 – 25
2	Viscosity, c' poise at 27°C	4,000 – 10,000
3	Linear shrinkage, max. %	0.1
4	Specific gravity, Min. Max.	1.05 1.20
5	Pot life, minutes, Varies with accelerator used, at 25 °C 30 °C 35 °C	90 minutes 60 minutes 45 minutes
6	Storage life	At least 12 months
(b) EPOXY RESIN MORTAR MIXTURE		
1	Moisture susceptibility	Slightly susceptible
2	Compressive strength 1:3 to 1:6 with fine and medium sand, kg/cm ²	350-1000 (2 days)
3	Tensile strength with fine sand (1:3 to 1:4), kg/cm ²	80-100 (2 days)
4	Flexural strength with fine sand (1:3 to 1:4), kg/cm ²	400-500 (7 days)
5	Bond strength both with fine and medium sand (1:3 to 1:6), kg/cm ²	25-45 (2 days)

12.7.3 The field moulded sealants may be cold or hot poured and further categorised under the following three types:

- (1) Thermoplastics, Hot Applied : Usually black in colour and include materials such as asphalts, rubber asphalts, coal tars and rubber tars
- (2) Thermoplastics, Cold Applied : Include acrylics and vinyls as basic material
- (3) Thermosetting, Chemically-Curing Compounds : Usually one or two component systems and include polysulphide, silicone and polyurethane and epoxy based materials

12.7.4 There are many liquid joint sealant materials available in India, but each has its distinct characteristics, such as:

- a. Preparation time
- b. Workability/ease of placement.
- c. Curing
- d. Adhesiveness
- e. Cohesiveness
- f. Resistance to softening and flow
- g. Flexibility
- h. Elasticity
- i. resistance to aging and weathering, and resistance to weathering

12.7.5 The **Table 12.6** summarises the specification and relative costs of commonly used types of cold- and hot poured liquid (field moulded) sealants. This table also shows the design extension, or the extension that the installed sealant can withstand without being damaged and the shape factor. Further description and guidance is provided in **Appendix-C** and IRC:57.

Table 12.6- Various Specifications for Sealant Materials (Ref: 1.12, Table 1 and IRC:57)

Sealant Material	Applicable Specification		Design Extension	Shape Factor (Depth/Width)	Relative Cost (Ref: CRRI)
	BS/BIS	US			
PVC/Coal Tar		ASTM D 3406	10%-20%	1:1	3.0
Rubberised Bitumen	IS: 1834	ASTM D 1190		1.25:1	3.5
Polymeric Asphalt Based		AASHTO M 173 ASTM D 3405 AASHTO M301 ASTM 06690 Fed SS-S-140 I C	15%-20%	1:1 Overbanding Recommended	3.5
Polysulphide	BS: 5212 IS: 11433 (Part-I) 1985	Fed SS-S-200E AASHTOM282	10%-25%	1.25:1	4
Silicone		ASTM D 5893	30%-50%	1 : 1	7
Polyurethane	BS:5212	Fed SS-S-200 E	10%-20%		6
Other Specifications/Test Methods Found in IRC/NHAJ Documents		ASTM D 113 ASTM D 3583			

12.7.6 A primer shall be used according to the sealant manufacturer's recommendations for improving the adhesion between the sealing compound and old concrete.

12.7.7 A variety of backing rods and tapes are available in the market conforming to different specifications. Backer rods manufactured from material conforming to ASTM D 5249 Standard Specification for backer material for use with Cold and Hot Applied Joint Sealants in PCC pavements is recommended. Backer rods shall be oversized (by 25%) relative to the joint width so to provide firm resistance when applying the sealant, and also to prevent percolation of sealant in the contract underneath.

12.7.8 For all materials, the manufacturer's recommendations should be carefully considered and followed. Field adhesion tests to the joint substrate performed in accordance with the manufacturer's recommendations with their technical representative present is recommended. Warranties against adhesion and cohesive failure should be considered whilst preparing the contract documentation.

12.7.9 Preformed compression seals are made from neoprene rubber and have an internal web structure so that the material remains compressed in the joint. The joint seal shall conform to ASTM D 2628 with the properties as given in **Table 12.7** (IRC:57).

Table 12.7 Requirements for Preformed Compression Seals

S. No.	Description	Requirements	ASTM Test Methods
1	Tensile Strength, min .	13.8 Mpa	D412
2	Elongation at break	min. 250%	D412
3	Hardness, Type A durometer	55 +/- 5 points	D2240
4	Oven aging, 70 h at 100°C Tensile strength loss	20% max	D573
5	Elongation loss	20% max	
6	Hardness Change Type A durometer	0 to + 10 points	D471
7	Oil Swell, ASTM Oil 3, 70 h at 100°C weight Change	45% max	D1149
8	Ozone resistance 20% strain, 300 pphm in air, 70 h at 40 °C	No cracks	D2240
9	Low temperature stiffening, 7 days at -10°C Hardness Change type A durometer	0 to + 15 Points	
10	Low temperature recovery, 22h at -10°C, 50% deflection	88% min	D2628
11	Low temperature recovery, 22h at -29°C, 50% deflection	83% min	D2628
12	High temperature recovery, 70h at 100°C, 50% deflection	85% min	D2628
13	Compression, deflection, at 80% of normal width (min)	613 N/m	D2628

12.8 New Materials

New concrete repair materials based on chemical formulations have surfaced in the local market in India. These are proprietary items. Proprietary firms are advocating an effective and fast result, particularly in the area of minor crack repairs. The present guidelines do not make any recommendations about the same. Highway Agencies may consider using them on selective basis after being satisfied about them and reporting about their performance to IRC for evaluation and wider publication after acceptance.

13 TOOLS AND PLANT

13.1 General

13.1.1 A list of equipment that will be generally needed for various types of repair work on cement concrete pavements is given below. In addition, it may be necessary to have mobile units located at Key places so that the repair work may be centralised and handled expeditiously.

For this purpose, a truck wherein a small hand operated drum/jiffy mixer, vibratory tamping equipment, and some small essential tools are provided, can be very useful.

13.2 List of Tools and Equipment for Different Types of Repair

13.2.1 Joint resealings

- (i) Plough for removing old sealant
- (ii) Wire Brushes
- (iii) Sand blasting equipment, air compressor with in-line filters to trap oil and water, hoses, 6 mm venturi-type tube
- (iv) Broom and/or power vacuum
- (v) Backer rod installation tool/roller wheel
- (vi) Sealant applicator equipment (and mixing head for two component systems)
- (vii) Pail mixer
- (viii) Plastic measuring beakers
- (ix) Masking Tape
- (x) Trowels
- (xi) Personal safety equipment (i.e. gloves, masks, safety vest first air box etc.)
- (xii) Saw cutting machine with diamond blades

13.2.2 Crack repair and cross-stitching

- (i) Random crack saw (130 mm dia diamond blades)
- (ii) Vertical spindle router (belt drive)
- (iii) Single headed scabbling tool or router (crack cutter)
- (iv) Template
- (v) Small portable generator
- (vi) Portable air compressor Min. 71 litres/sec at 0.55 N/mm²
- (vii) Rotary impact hammer drill
- (viii) Trowels and floats
- (ix) Personal safety equipment (gloves, masks, safety vest first air box etc.)

13.2.3 Spall repair

- (i) Concrete saw (170 mm to 250 mm dia diamond blades for large patches, 130 dia for small patches)
- (ii) 170 to 250 Portable air compressor Min. 71 litres/sec at 0.55 N/mm²
- (iii) Electric chisel
- (iv) Club Hammer (4 kg)
- (v) Cold Chisels
- (vi) Pail mixer, hand held or paddle wheel
- (vii) Mixing pails, small

- (vii) Plastic measuring beakers
- (viii) Masking Tape
- (x) Hand tools, shovel, trowels, tampers and screeds
- (xi) Personal safety equipment (i.e. gloves, masks, safety vest etc.)

13.2.4 Full depth and whole slab replacement repairs

- (i) 50-60 H.P. diesel or petrol mobile concrete saws (smaller machine may be suitable for limestone aggregate concrete)
- (ii) 750-1000 mm dia. diamond saw blades for full depth repair and 300 – 450 mm dia diamond saw blades for partial depth repair (**Fig. 13.1**)
- (iii) Portable air compressor min 118 litres/sec at 0.55 N/mm and concrete breaking tools/jack hammer (14 kg)
- (iv) Heavy duty wire cutters or bolt croppers
- (v) Small portable generator
- (vi) Rotary drill
- (vii) Club hammer (4 to 6 kg)
- (viii) Cold chisels
- (ix) Drilling jig or frame
- (x) Welding equipment (for continuously reinforced slabs)
- (xi) Frame for holding dowel bars in position until resin mortar hardens (jointed slabs)
- (xii) Poker vibrator(s)
- (xiii) Vibrating finishing beam (for leveling surface uniformly)
- (xiv) Wire Tyne (for surface texturing)
- (xv) Trowels, floats and arising tool

13.3 Saw Blade Selection

13.3.1 The saw blade for cutting concrete must be compatible with the output and speed of the saw, concrete strength and application.



(a) 450 mm Dia Blade for PDR



(b) 1000 mm Dia Blade for FDR

Fig. 13.1 Different Size Saw Blades for Concrete Cutting

14 PLANNING THE MAINTENANCE OPERATIONS

14.1 General Objectives

14.1.1 The general principles and objectives of highway maintenance as it particularly concerns the preservation of concrete pavements is dealt with in this section.

14.1.2 Concrete pavements generally deteriorate gradually in life (5- 25 years) and deteriorate quicker as they approach the effective service life (30- 40 years). Refer **Fig. 1.6** in Chapter 1. Spot repairs and restoration of isolated parts are performed to prevent or slow the overall deterioration of the concrete pavement.

14.1.3 The deterioration can affect the whole pavement structure beyond the effective service life and therefore also affect the safety and comfort of the user and the maintenance costs. Earlier intervention to restore its condition before there is significant drop in pavement servicability should be the objective of the maintenance strategy. The maintenance and repair of concrete roads is therefore as essential as that of any other concrete structure.

14.2 Organisation and Management

14.2.1 The maintenance of Highway Pavements generally embraces all the activities illustrated in **Fig. 14.1**.

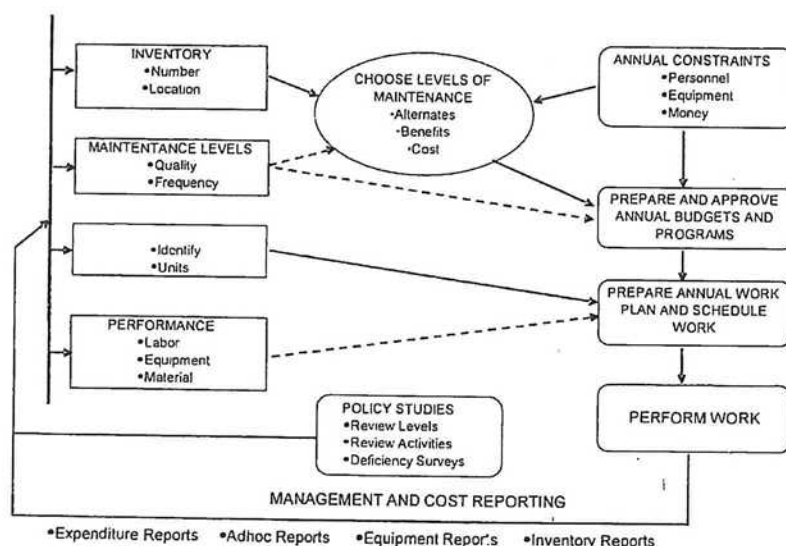


Fig. 14.1 Schematic Diagram of Maintenance Management System

14.2.2 Maintenance of a road requires proper supervision of skilled workmen who are adequately trained in various aspects of maintenance. The supervisory staff generally known as junior engineers in this country, is therefore to be given training in various aspects of cement concrete pavement work. They should be conversant with the specifications for various types of repair works, the choice of repair, the quality control measures needed to achieve good workmanship, use and upkeep of equipment and tools and safety measures to be adopted during the maintenance operations.

14.2.3 Planning and scheduling of the maintenance operations should be given due importance. The annual renewal programme should be drawn up well in advance keeping in

view the condition of the surface, prescribed renewal cycle and any improvement work carried out recently or scheduled to be taken up in the near future. It is useful for easy comprehension to depict the renewal programme on bar chart indicating the renewals carried out in the last eight years. The budgeting for maintenance expenditure should also be done well in advance and the allocation of resources to the different operations of maintenance should be finalised simultaneously. This would facilitate the field engineer to plan and implement his programme effectively.

14.3 Periodical Monitoring

14.3.1 The Table 14.1 lists the types of formal inspections and surveys with recommended frequencies.

Table 14.1 Types and Frequency of Inspections

S. No.	Type of Maintenance Inspection	Recommended Frequency
1	Project Preparation Survey	Performed by (or on behalf of) the Client for drawing up the scope of work for the maintenance Contract.
2	Initial Condition Survey (Contract)	Within 28 days of taking over or signing the maintenance contract (whichever is applicable)
3	Safety Inspections	Not less than once a week on National and State Highways, and fortnightly on all other roads
4	Intervention Inspection	Once a week, and on at least one occasion accompanied by Deputy Collector and DSP for controlling encroachments etc.
5	Bridges, Culverts and Drains Inspection	On a regular basis, according to availability of qualified inspectors but not exceeding six (6) months. Note: NHAI guidelines specify three (3) months
6	Night Inspections	Periods not exceeding six months.
7	Annual Inspections	Highway pavement condition report including settlements, deflections and roughness condition of facilities such as bus shelters, buildings at Toll Plaza etc.
8	Completion Condition Survey (Contract)	Not later than 21 days prior to the Completion Date of the Contract

14.3.2 The pavement shall be periodically monitored since new distress may appear and existing distress propagate further.

14.4 Distress Identification and Classification

14.4.1 By early detection, classification and repair of defects in their initial stages the rapid deterioration of the pavement and its joints can be prevented.

14.4.2 The first step to planning a maintenance operation is the evaluation of the existing pavement in terms of its physical condition and both its functional and structural capacity. For this purpose, condition surveys should be undertaken for the visual assessment of the pavement, which would cover not only the type but also the magnitude of the distress and its location. Apart from visual surveys, pavement surface evaluation based on riding quality (i.e. road roughness) and skid resistance should also form the basis for taking maintenance decisions.

14.4.3 Necessary information about the routine maintenance needs will be readily available as the maintenance staff is expected to be continuously in touch with the physical condition of the road. However, for deciding periodic treatments and long term maintenance strategies, condition surveys carried out at a fixed frequency are a must. Keeping this in view, it is desirable that at least two condition surveys are conducted on each stretch of road every year, one before and the other after the monsoon i.e. the same frequency as with flexible pavements. Generally the condition surveys are carried out on foot because cracking and joint problems may not be discernible from a vehicle even if travelling at a slow speed. The data collected should be recorded methodically kilometer wise. It is desirable that these visual surveys are carried out by an experienced engineer at a responsible level. See Chapter 4 **Proforma 4.3**.

14.4.4 Based on the condition evaluation, the causes for the various defects observed should be examined in detail as discussed in Chapter 4 and a decision taken whether to initiate a particular maintenance activity, defer the same or to go in for more detailed investigations to determine the treatment/rehabilitation needs precisely. Where distress on the pavement has reached the stage of pot holing, spalling and/or the slabs are rocking under traffic which affects the smooth operation of traffic, it should be rectified straightway. For other defects like cracking, ravelling etc., the optimal strategy should be determined having regard to the various factors involved including the finances available and a decision taken whether to go in for temporary measures like sealing/resurfacing or to strengthen/reconstruct the pavement. If the latter appears necessary, further investigations about structural deficiencies shall be taken up as mentioned in Para 4.4. In other words the planning of the various maintenance operations should be correlated and looked upon as a total system rather than each activity being considered in isolation. There can be sometimes more than one strategy to address a distress problem.

14.4.5 Once the overall maintenance plan has been drawn up, attention should be given to the proper organisation management of the whole programme including deployment of various resources, i.e. men, materials and equipment, in an efficient manner. For each maintenance activity the work at site should be carefully controlled so that the optimum output and quality are achieved.

14.5 Performance Standards for Maintenance

14.5.1 The general objective of road maintenance is to provide a clear and smooth ride so traffic may pass safely and comfortably. The performance standards define the level at which the facility is to be maintained.

14.5.2 *Maintenance standards should consider the following:*

- a. Traffic data (volumes and axle loading)
- b. Surface texture

- c. Drainage condition
- d. Cracking
- e. Shoulder drop-off
- f. Slab warp
- g. Spalling
- h. Slab settlement, faulting
- i. Heave or distortion
- j. Settlements at bridge approaches
- k. Sub-base failure
- l. Joint separation
- m. Joint sealing
- n. The need to minimise traffic disruptions

14.5.3 The basis of maintenance standards set out in this Guideline is based on the following fundamentals:

- (a) **Pavement surface** - The pavement surface shall be kept thoroughly clean as part of the routine maintenance program at a minimum frequency of twice a year in rural stretches and four times a year in the habited/built up stretches so to protect the concrete surface from accelerated abrasion and to prevent stones lodging in and damaging joints (**Table 14.2**).

Stones and other debris on the carriageway are a safety hazard (causing broken windshields and swerving of vehicles to avoid larger debris) and damage the pavement surface. Soil and other debris accumulated beside kerbs and chute drains in median and beside barrier kerbs etc. prevents free drainage of water increasing the risk of damage under traffic.

Table 14.2 Cleaning of Concrete Pavement

Job Description	Criteria Extent (% sub-section length)	Location/ Side	Treatment/ Action	Type of Maintenance
Pavement cleaning (sweeping) including removal of litter rubbish and other debris	a) Minimum twice a year, or b) When exceeding 25% in any 20 m long stretch.	All	Sweep, wash and dispose	Routine
	b) When accumulation prevents the free drainage of water from the pavements, kerbs and channels.	All	Remove and dispose off site.	Urgent i.e. Within 2 days of detection

- (b) **Cracks** - Individual cracks 3 mm wide and any other areas with extensive finer cracking shall be repaired before the rainy season to prevent infiltration of water into the foundation layers.
- (c) **Settlement, Heave, Distortion, Faulting** - Correction of surface irregularities shall be scheduled when the surface deviation reaches 38 mm in a length of

2.5 m or when the riding quality is objectionable (> 4000 mm/km). This type of defect otherwise results in poor riding quality and extra loading on the slabs which accelerates pavement deterioration. Diamond grinding shall be applied when the level difference between two slabs across a joint or cut becomes more than 4 mm.

Regular inspection below approach slabs at bridges is also very necessary to detect signs of voids under the slabs and/or springyness/pumping. Settlement of approach slab is otherwise likely to occur. Early detection and filling of voids can often prevent slab settlement.

- d) **Spalling** - Transverse spalling exceeding 100 mm in the direction of travel and more than 6 mm deep or other similar type defects which induce extra loading on the slabs and adversely affect comfort shall be repaired.
- e) **Joint separation** - separation between the concrete slabs exceeding 3 mm shall be filled to prevent infiltration of water into the foundation layers. Similar separation/erosion occurring between the interface of concrete pavement and paved/unpaved shoulder should also be tilled up/repared promptly to prevent run off further eroding and eventually undermining the edge of the concrete pavement.

14.6 Training

14.6.1 The MoRT&H Specifications for Road and Bridges specifies the importance of building in quality assurance into the planning and execution of all the works including the pavement works.

QUOTE "The Contractor shall ensure that all the actions are taken to build in quality assurance in the planning and execution of the works. The quality assurance shall cover all stages of work such as setting-out selection of materials, selection of equipment and plant, deployment of personnel and supervisory staff, quality control testing, etc."

END OF QUOTE (Ref: Clause 105.3).

14.6.2 Training is an integral part of Quality Assurance. The Contractor should get his staff trained for the following through Seminars and Training workshops:

- (i) Durable concrete pavement mix design (for partial/full depth replacement and full panel replacement).
- (ii) For pavement evaluation and identification of distress/severity rating
- (iii) For cleaning of joints
- (iv) For priming of joint groove and installation of sealants
- (v) Marking of repair boundaries, hacking out distressed concrete and refilling of concrete and epoxy concrete/quick setting cementations materials

14.6.3 The training of staff should therefore form an essential part of the execution of any maintenance strategy. The owner of the pavement should make it mandatory to make provision in the contract/document for training of Contractors' staff so that the diagnosis of the cause and quality of the repair job is assured.

15 ARRANGEMENT FOR TRAFFIC AND SAFETY

15.1 Traffic Control

15.1.1 Since maintenance operations involve considerable hardship, inconvenience and hazard to traffic and also hazards to maintenance workmen, all possible precautions should be taken to make safe arrangements for traffic. These include erection of barriers, signs, red flags and lights including flickering caution lights. Efforts should be made to confine work in half the pavement width at a time, leaving the other half for use by the traffic. Where this is not possible, diversion roads may have to be constructed or the traffic diverted to some other alternative routes. The maintenance operation itself can be conveniently confined to a small length at a time, say 30 m.

15.1.2 Traffic diversion shall be planned and implemented in accordance with the recommendations of IRC:SP:55 "Guidelines on Traffic Management in Work Zones". The lettering shall be legible from a speeding vehicle at 100 m. Traffic signs should be of no less than 900 mm x 600 mm in case of rectangular signs and 900 mm in case of circular and triangular signs.

15.1.3 The traffic shall be clearly warned sufficiently in advance. The appropriate warning sign to be used is the "Man at work" sign, as per IRC:67 "Code of Practice for Road Signs". If half the road width alone is available for traffic, the "Narrow Road Ahead" sign should also be displayed. If closure extends into the night or several days, the signs shall be retro-reflective by an approved manufacturer. During night in urban stretches, (and where practical in rural stretches) there should be adequate lighting with a red lantern/red reflectors. Adequate ward and watch shall be provided to prevent stealing of all the traffic control devices.

15.2 Safe Working Environment

15.2.1 The safety of the worker shall also be addressed in the program. Job instructions shall include safety items that should be addressed while undertaking repairs. These should include:

- (a) Use of high visibility clothing
- (b) Correct lifting techniques
- (c) Understanding hazardous materials used and correct mixing and application
- (d) Moving vehicles outside the site
- (e) Correct use and handling of plant
- (f) Awareness of underground and or overhead cables and utility services
- (g) Availability and general awareness of First Aid Kits

LIST OF REFERENCES

A.1. List of IRC Publications and Indian Standards

- (1.1) IRC:61-1976 "Tentative Guidelines for Construction of Cement Concrete Pavements in Hot Weather"
- (1.2) IRC:77-1979 "Tentative Guidelines for Repair of Concrete Pavement Using Synthetic Resins"
- (1.3) IRC:84-1983 "Code of Practice for Curing Cement Concrete pavements"
- (1.4) IRC:SP:17-1997 "Guidelines for the Overlay Design (Composite Pavement Construction)"
- (1.5) IRC Special Publication, 2001, "Report of the Committee on Norms for maintenance of Roads in India"
- (1.6) IRC:67-2012 "Code of Practice for Road Signs"
- (1.7) IRC:SP:55-2014 "Guidelines on Traffic Management in Work Zones"
- (1.8) IRC:15-2017 "Code of Practice for Construction of Jointed Plain Concrete Pavements" (Fifth Revision).
- (1.9) IRC:58-2015 "Guidelines for the Design of Plain Jointed Rigid Pavements for Highways" (Fourth Revision)
- (1.10) IRC:SP:16-2004 "Guidelines for Surface Evenness of Highway Pavements"
- (1.11) IRC:57-2018 "Recommended Practice for Sealing of Joints in Concrete Pavements" (Second Revision)
- (1.12) IRC:43-2015 "Recommended Practice for Plants, Tools and Equipment Required for Construction and Maintenance of Concrete Roads" (First Revision)
- (1.13) IS:11433 (Part 1) 1985:Specification for One Part Gun-Grade Polysulphide Based Joint Sealants
- (1.14) IS:516 Methods of Test for Strength of Concrete

Where, IRC = Indian Roads Congress

IS = Bureau of Indian Standards

A.2 List of AASHTO, British and ASTM Standards

- (2.1) AASHTO M 173, Concrete Joint Sealer, Hot Poured Elastic Type
- (2.2) AASHTO M 282, Joint Sealant, Hot poured, Elastomeric Type
- (2.3) AASHTO M 301, Joint Sealant, Hot poured for Concrete and Asphalt Pavements

- | | | |
|--------|---|-------|
| (2.4) | ASTM C 39, Compressive Strength of Cylindrical Concrete Specimens | (3.6) |
| (2.5) | ASTM C 150, Portland Cement | (3.7) |
| (2.6) | ASTM D 1190 Concrete Joint Sealer, Hot Applied Elastic Type | |
| (2.7) | ASTM E 274, Skid Resistance of Paved Surface Using Full Scale Tire | (3.8) |
| (2.8) | ASTM E 950, Measuring Longitudinal Profile with an Accelerometer | |
| (2.9) | ASTM E 1364, Measuring Road Roughness by Static Level Method | A.4 |
| (2.10) | ASTM D 3405, Joint Sealants, Hot Applied for Concrete | (4.1) |
| (2.11) | ASTM D 3406, Joint Sealants, Hot Applied Electrometric Type for Portland Cement Concrete | (4.2) |
| (2.12) | ASTM D 3575, Flexible Cellular Materials (For Sealant Backing Rods) made from Olefin Polymers | (4.3) |
| (2.13) | ASTM D 5893, Cold Applied Single Component Chemically Curing Silicone | (4.4) |
| (2.14) | ASTM D 6690 (part 1), Joint and crack sealant, Hot Applied, for Concrete and Asphalt Pavements | (4.5) |
| (2.15) | BS: 5212 (part 2), Cold cured joint sealants for concrete pavements | Wh |
| (2.16) | BS: 7542 Method of Test for Curing Compound for Concrete | |
| (2.17) | AASHTO-AGC-ARTBA Task Force-36 "The Use and State-of-the-Practice of Fiber Reinforced Concrete" | |

Where, AASHTO = American Association of State Highways and Transportation Officials
 ASTM = American Society for Testing and Materials

A.3 List of Other References

- | | |
|-------|---|
| (3.1) | Aerodrome Design Manual (DoC 9157-AN/901) Part 3 - Pavements Second Edition 1983 |
| (3.2) | H. S. Mildenhall, G. D. S. Northcott, Department of Transport, Cement and Concrete Association, 1986, A Manual for the Maintenance and Repair of Concrete Roads, London, HMSO |
| (3.3) | Committee of State Road Authorities, Pretoria, South Africa, 1990, Standard Nomenclature and Methods for Describing the Condition of Jointed Concrete Pavements, Technical Recommendations for Highways, Draft TRH19:1989 |
| (3.4) | Mohamed Y. Shahin, 1994, Pavement Management for Airports, Roads and Parking Lots, Chapman & Hall, New York, London |
| (3.5) | Gerald F. Voigt, 2000, Specification Synthesis and Recommendation for Repairing Uncontrolled Cracks that Occur during Concrete Pavement Construction, American Pavement Concrete Association (ACPA) |

- (3.6) US Federal Highway Administration, Report No.FHWA-01-00080 "Repair and Rehabilitation of Concrete Pavements", Sept 2004
- (3.7) US Federal Highway Administration, Technical Brief No. FHWA-IF-06-005 " Concrete Pavement Rehabilitation and Preservation Treatments", November 2005
- (3.8) US Federal Highway Administration, Concrete pavement Rehabilitation Guide for Diamond Grinding, May 2006

A.4 List of ACPA Standards

- (4.1) TB018P --"Slab Stabilization Guidelines for Concrete Pavements"
- (4.2) TB002.02P --" Guidelines for Full Depth Repair"
- (4.3) TB008.01P-- "Diamond Grinding and Concrete Pavement Restoration"
- (4.4) TB020.02P-- "The Concrete Pavement Restoration Guide"
- (4.5) TB016.01P-- "Early Cracking of Concrete Pavement—Causes and Repairs"




Where ACPA = American Concrete Pavement Association

CONCRETE MIX CHARACTERISTICS FOR EOT PROJECTS

Year	Place	Mixture Proportions	Compressive Strength (ASTM) converted to Cube strength (MPa)	Flexural Strength (MPa)	Notes
1990	Northampton County, Virginia, USA	Cement (type I, ASTM): 445 kg/cm W/C : 0.42 Coarse aggregate: 1113 kg/cm Fine aggregate: 620 kg/cm Max. aggregate size: 25 mm Water reducer: AASHTOM 194 Air entrained: 5.5 %	18 hours: 32 24 hours: 36 7 days: 50 28 days: 60	28 days: 5.6	Opened to traffic after 58 hours; traffic amount of 240 equivalent single axle load per day
1991	Dallas County, Iowa, USA	Cement: 298 kg/cm Fly ash: 56 kg/m Coarse aggregates: 914 kg/cm Fine aggregate: 933 kg/cm Water reducer: 2.6 ml/kg Air entrained: 0.56 ml/kg	28 days: 34	28 days: 4.7	
1991	Louisville Kentucky, USA	Cement (type I, ASTM): 475 kg/cm W/C : 0.33 Coarse aggregate: 1067 kg/cm Natural sand : 948 kg/cm Water reducer: (ASTM C-494): 1.1 kg/100 kg Air entrained: 4 to 6% Polypropylene fibres: 1.78 kg/cm	18 hours: 34	-	Waste disposal facility: 90 trucks per day; opened to traffic after 37 hours
1994	Gerogetown Kentucky, USA	Cement (type I): 475 kg/cm W/C : 0.32 60% - 40% ratio of coarse aggregate and natural sand water reducer: 0.98 ml/100 kg Air entrained: 5.5 %	24 hours: 31	-	Stretch Intersection
1994	State Route 21, Iowa, USA	Cement: 340 kg/cm W/C : 0.43 Coarse aggregate: 986 kg/cm Fine aggregate: 809 kg/cm Air entrained: 6 % Synthetic fibers: 1.36 kg/cm	-	-	Opening to traffic 5-7 days

Year	Place	Mixture Proportions	Compressive Strength (ASTM) converted to Cube strength (MPa)	Flexural Strength (MPa)	Notes
1995	Leawood Kansa, USA	Cement (type I): 363 kg/cm W/C : 0.37 Coarse aggregate: 1026 kg/cm Fine aggregate: 798 kg/cm Max. aggregate size: 25 mm Air entrained: 6.5 % Synthetic fibers: 1.36 kg/cm	24 hours: 26	-	Opened to traffic 24 hours; mixed traffic of 25,000 vehicles per day
1995	Tennessee & Dckalb Co., GA, USA	Cement: 474 kg/cm W/C : 0.35 Coarse aggregate: 1008 kg/cm Fine aggregate: 730 kg/cm Synthetic fibers: 1.36 kg/cm	24 hours: 43 (achieved)	-	-
1995	Lexington, Kentucky, USA	Cement (type I): 475 kg/cm Coarse aggregate: 1067 kg/cm Natural sand: 948 kg/cm Max. aggregate size: 25 mm Water reducer: (ASTM C-494, type F): 0.98 ml/100 kg Air entrained: 5 % Synthetic fibers: 1.36 kg/cm	24 hours: 30 36 hours: 42 48 hours: 44 7 days: 56 28 days: 64	24 hours: 5.2 36 hours: 5.8 28 days: 7.1	

**PHOTOGRAPHS ILLUSTRATING COMMON TYPES OF DEFECTS AND SUGGESTED
TYPICAL REPAIR TECHNIQUES AS PER THE DISTRESS SEVERITY**

	<p align="center">FULL DEPTH REPAIR (Width of Repair 1.5 m minimum)</p> <p>Note: example illustrated caused by Blowup Severity Rating 5</p>
<p align="center">Photo 1 Blowup and Transverse Cracking</p>	<p align="center">Recommended Treatment As Above</p>
	<p align="center">One Corner Break EPOXY CONCRETE REPAIR (LOCAL)</p> <p align="center">Two Corner Breaks FULL DEPTH REPAIR (1.5 m minimum)</p> <p>Note: Severity Rating 4 is illustrated in example</p>
<p align="center">Photo 2 Deep Corner Break</p>	<p align="center">Recommended Treatment as Above</p>
	<p align="center">SEAL WITH LOW VISCOSITY EPOXY See Para & Fig. 5.1</p> <p>Note: Severity Rating 2 is illustrated in example</p>
<p align="center">Photo 3 Shallow Corner Break</p>	<p align="center">Recommended Treatment as Above</p>



**Severity Rating < 3
CROSS-STICHING See Fig. 5.1 (Para)**

Photo 4 Longitudinal Crack

**Severity Rating 3 or more
WHOLE SLAB REPLACEMENT**

Note: The condition of the slabs illustrated here treated with Cross-Stitching deteriorated further under traffic after monitoring for 6 months.

All cracked slabs were finally replaced in total (whole full depth) during the DLP.

Recommended Treatment As Above.

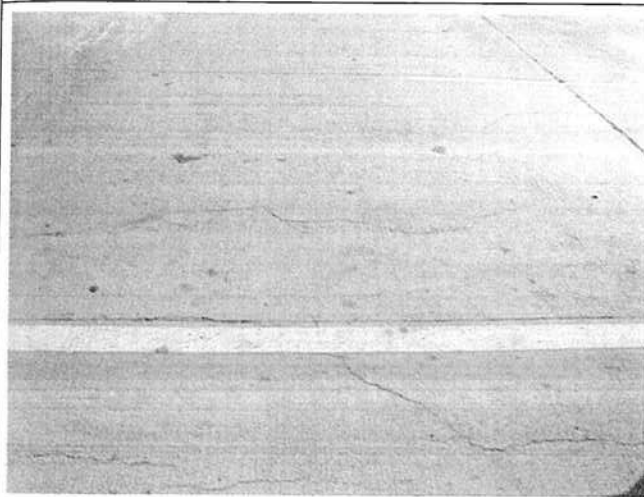


Photo 5 Multiple Connecting Cracks

WHOLE SLAB REPLACEMENT

Note: Severity Rating 3 is illustrated in example.

Recommended Treatment As Above

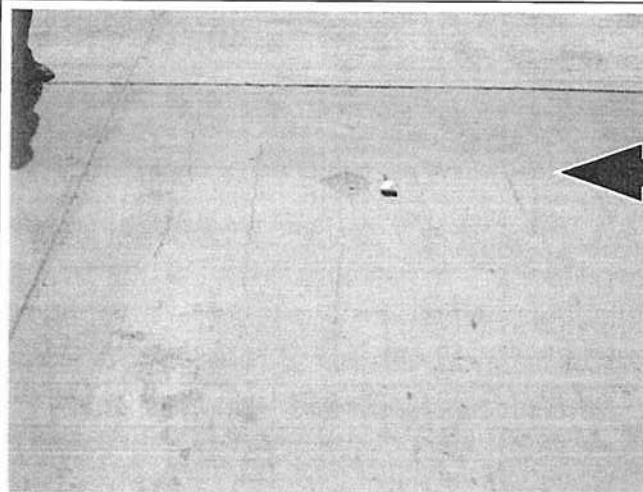


Photo 6 Discrete Plastic Shrinkage Cracks

**WIND
DIRECTION**

SEAL WITH LOW VISCOSITY EPOXY

Note: Severity Rating 2 is illustrated in example

Recommended Treatment As Above

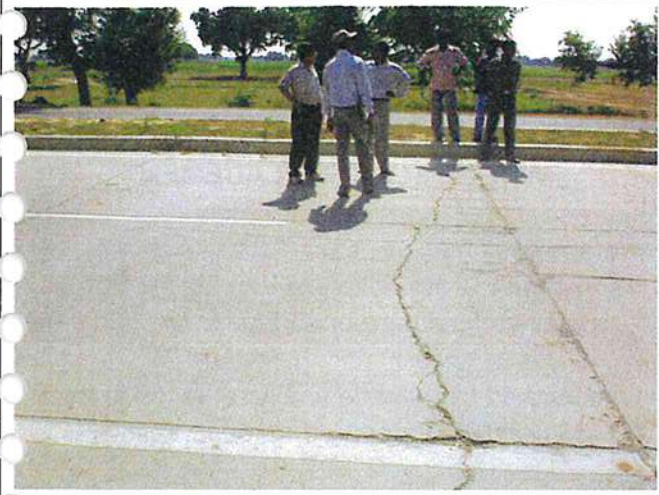


	<p>FULL DEPTH REPAIR (Width = 1.5m, Minimum) See Fig. 5.1 (Para)</p> <p>Note: Severity Rating 4 is illustrated in example</p>
<p>Photo 7a Transverse Crack Near Joint</p>	<p>Recommended Treatment As Above</p>
	<p>A) WHOLE SLAB REPLACEMENT For New Construction (DLP) or B) CHIP AND SEAL MONITOR AS WORKING CRACK SHORT TERM MEASURE For Old Concrete Panels</p> <p>Note: Severity Rating 4 is illustrated in example</p>
<p>Photo 7 b Transverse Crack Near Middle (1/3rd)</p>	<p>Recommended Treatment As Above</p>
	<p>ROUTE GROOVE AND APPLY FLEXIBLE SEALANT</p> <p>MONITOR PERFORMANCE</p> <p>Note: Example illustrated is treatment on 50 year old concrete slabs constructed (Oct/1952) in medium trafficked urban environment.</p>
<p>Photo 8 Working Crack</p>	<p>Recommended Short Term Measure</p>



Photo 9 Drop Off

**SCARIFY AND FILL UP WITH A WEAR
RESISTANT TRAFFICABLE GRAVEL**
(CBR > 30, PI in range 3 – 12)

When Dropoff in any 100m stretch
> 40 mm For NH/SH
> 70 mm For Other Roads

See Table 4.4

Recommended Treatment



Photo 10 Impressions Early Traffic Damage

**Severity rating < 2
DO NOTHING**

**Severity Rating > 3
LOCAL EPOXY MORTAR REPAIR**
To DEPTH 65 mm with 20 mm Drill Holes for
"Key"

Note: Example illustrated has Severity Rating 3

Recommended Treatment



Photo 11 Manhole/Inlet Cracking Failure

Cracking and/or faulting caused by restrained
thermal movements around or settlement below a
manhole or inlet.

**FULL DEPTH REPAIR IN REGULAR
SHAPE
WITH REINFORCEMENT**

Recommended Treatment



Photo 12 Pop Out

EPOXY MORTAR REPAIR

See Fig. 5.1

Note: Severity Rating 3 is illustrated in example

Recommended Treatment As Above



Photo 13 Punchout (CRCP only)

SHAPE MERGEFORMAT

Water trapped under edge of CRCP at Matching point with Paved Shoulder causing cracking and punching out under heavy traffic loading

**IMPROVE DRAINAGE BELOW BASE AND
RECONSTRUCT
FULL DEPTH PATCH**

Recommended Treatment As Above



**Photo 14 Ravelling
(lose of laitance/fine aggregates in surface)**

**Severity Rating < 4
DO NOTHING**

**Severity Rating 5 or more
WHOLE SLAB REPLACEMENT**
For New Construction (DLP)

MILL & PLACE BONDED OVERLAY
Trial For Old Construction

Note: Severity Rating 5 is illustrated in example

Recommended Treatment

**Photo 15 Scaling**

Severity Rating < 2
PARTIAL DEPTH REPAIR

Severity Rating 3 or more
WHOLE SLAB REPLACEMENT

Note: Severity Rating 3 is illustrated in example

Recommended Treatment

**Photo 16 Joint Sealant Failure**

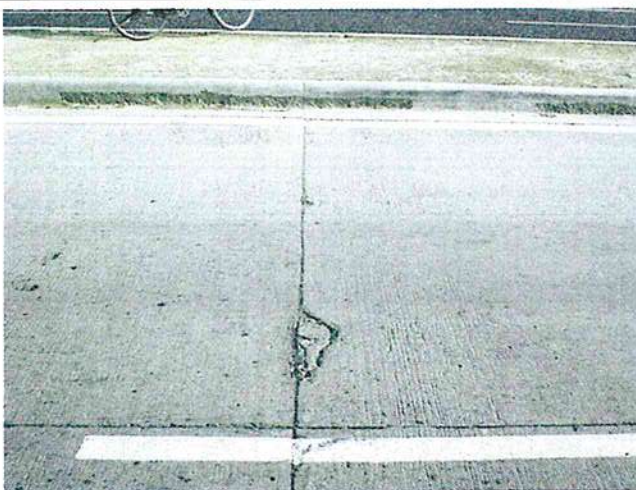
Cause of adhesion failure : loss of sealant bond/
adhesion to sides caused by separation of slabs.

Severity rating < 2
DO NOTHING

Severity Rating > 3
RESEAL WHERE FAILURE/DAMAGE
EXCEEDS 25% OF JOINT LENGTH

Note: Example illustrated is Severity Rating 4 at a
Longitudinal Joint

Recommended Treatment

**Photo 17 Shallow Spalling at Joint**

PARTIAL DEPTH REPAIR

Note: Severity Rating 4 is illustrated in example
(> 60 x 10 cm)

Maximum Surface Area	Minimum Depth	Patch Material
< 0.5 m ²	30 mm	Elastomeric Concrete
> 0.5 m ²	100 mm	Epoxy Concrete

Recommended Treatment




	<p>Cause: Misalignment of dowel bars, Inadequate compaction and/or Compression Failure</p> <p>FULL DEPTH REPAIR (1.5 m) EACH SIDE OF JOINT</p>
<p>Photo 18 Deep Spalling at Joints</p>	<p>Recommended Treatment</p>
	<p>Cause : Inadequate compaction and Finishing 2nd Days concrete versus 1st Days concrete. Deficiencies vide:</p> <ul style="list-style-type: none"> • Levelling • Finishing • Compaction <p>FULL DEPTH REPAIR (1.5 m minimum) ONE SIDE ONLY</p>
<p>Photo 19 Cracking and Scaling at Construction Joint</p>	<p>Recommended Treatment</p>
	<p>PARTIAL DEPTH REPAIR (MINIMUM WIDTH 100 mm x 65 mm DEEP)</p>
<p>Photo 20 Expansion Joint Damage</p>	<p>Recommended Treatment</p>



Photo 21 Shattered Slabs

**Severity Rating 5
WHOLE SLAB REPLACEMENT**

Recommended Treatment



Photo 22 Cracking of DLC Below PQC

WHOLE SLAB REPLACEMENT
With Reinforcement added in Top
(as precaution against reflective cracking)

**DLC only requires replacement if in a
shattered state.**

Recommended Treatment



Photo 23 Compressive Seal - Loosening

Cause: Adhesion Failure and/or Vandalism

**SEAL TO SECURE ENDS
WITH COMBATABLE LIQUID SEALANT.**

Recommended Treatment

**Photo 24 Spalling along the Joint**

The unsound area will be marked with colored marker after sounding with hand held hammer. It will Saw Cut with light weight Concrete Saw cutter. The chisel will also be used to cut & take out the debris. The pit will be air cleaned and filled with epoxy concrete/PCC depending upon depth of spall.

Recommended Treatment

**Photo 25 Shallow Corner Break**

Full Depth repair after removing unsound and cracked concrete.

Recommended Treatment

**Photo 26 Pit Cut out for Partial Depth Repair**

Fill the Pit with Epoxy Concrete/Quick Setting Cementitious Material depending upon the depth of the cut

Recommended Treatment



Epoxy mortar failed after 12 Years

Deepen & Widen the Pit and repair with quick setting Cementitious Material

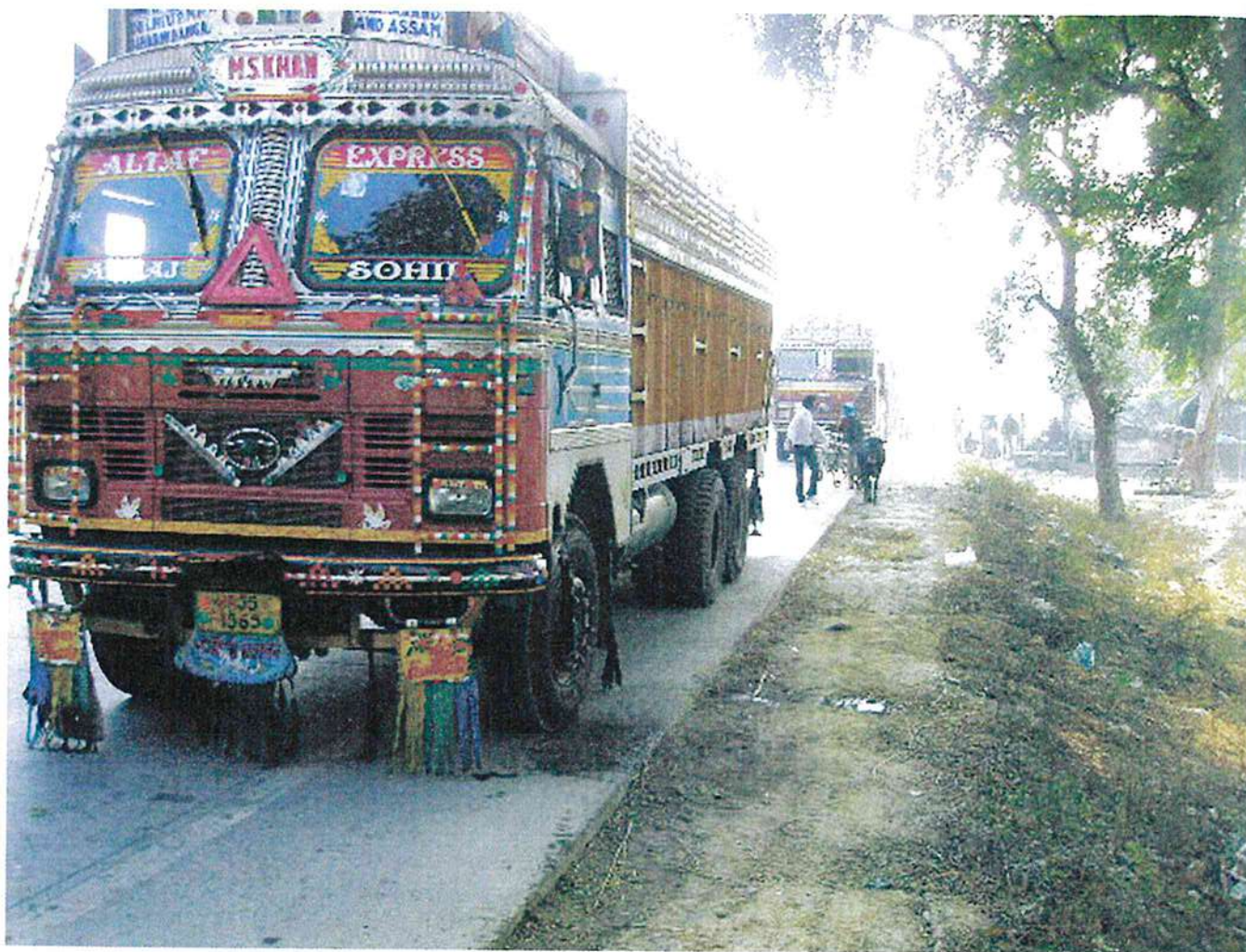
Photo 27 Partial Depth Repair Failure

Recommended Treatment

TREATMENT AND UPGRADING OF ERODED SOFT EARTHEN SHOULDERS

The narrow soft earthen shoulders typically observed on State and National Highway projects are important design shortcoming.

The MoRT&H Clause 305.2.1 provides for a mixture of soil, moorum, and gravel but the designers generally keep the specification for the earthen shoulder the same as for sub-grade material as in the case illustrated below which specifies a material satisfying the design CBR of 6%.



**Photo 1 Erosion, Wear and Tear of Soft Earthen Shoulder.
Trucks preferring to park on outer lane.**

Shoulders should however provide lateral support to the edges of the pavement, be of sufficient width and strength to support the parking of heavy vehicles under all weather conditions, shed off water, be durable and protect the lateral sub-drainage to the pavement below. Soft soil shoulders cannot comply with such requirements.

Soft shoulders are easily eroded. After erosion they do not provide comfortable walk for pedestrians, cannot provide a margin for error to avoid accidents nor be used by vehicles for parking. The erosion of shoulders is both superficial and internal and such erosion seriously undermines the embankments if left untreated which is often the case in rural areas.

Erosion is often more severe at the interface of paved to unpaved shoulder. Transverse erosion/gulying of shoulders can develop by piping and often be concealed by poor control of over growth.

The severity of soft shoulder's erosion will increase after every rainy season and a situation will be created where the edges of the flexible (and the rigid) pavement will be seriously undermined by lack of lateral support. **(Photo 2)**



Photo 2 Complete Erosion and Undermining of Rigid Pavement has Commenced

Proper treatment can be provided by turfing, brick on edge or from soil aggregate mixture.

Turfing the shoulder and whole side slope may prove satisfactory under certain climatic conditions as illustrated in the **Photo 3**.



Photo 3 Turfing on shoulder and side slope

Alternatively, soil aggregate mixtures may be procured from :

- (1) Borrow areas and mixed together so to comply with the specification recommended in the Table below,
or
- (2) Salvaged pavement sub-base and base materials recovered from the old (2-lane) pavement during the upgrading/widening to 4/6-lanes screened to discard oversized material (75%) and mixed together with a local moorum (25%) so to generally comply with a close graded GSB (Grading I) material. PI in the range 3 – 12%. (**Photo 4**).



Photo 4 Construction of Hard Shoulder with Recycled Sub-Base/Base Material Recovered from Existing Highway Mixed with Local Red Moorum (CBR>30).

It is further recommended that where the condition of existing soft shoulders is poor and unsatisfactory, the top 20 cm be replaced by hard granular shoulders with CBR > 30 as above as part of the engineering improvements proposed for the short term operations and maintenance contracts.

Recommended specification for special surface course gravel suitable for a trafficable unpaved shoulder are based on the materials described in the Technical Paper by N.B. Lal and S.C.Sharma^(Ref: 1).

Table D.1 - Typical Specification for a Trafficable Surface Course Gravel

Grading	Grading 1 - % passing	Grading 2 - % passing
	By N.B. Lal and S.C.Sharma	Suitable for mixture of salvaged base/sub-base (75%) and moorum (25%)
75		100
53		80 -100
26.5	100	55 - 90
19	97 - 100	
9.5		35 - 65
4.75	41 - 71	25 -55
2.36		20 - 40
0.425	12 - 28	10 - 25
0.075	9 - 16	3 - 10
Soaked CBR	> 30	> 30
PI in the range 3 – 12 according to the climatic conditions		

Alternatively, brick-on-edge paving complying with local State PWD specifications will provide a more durable but slightly more expensive solution. (**Photo 5**).

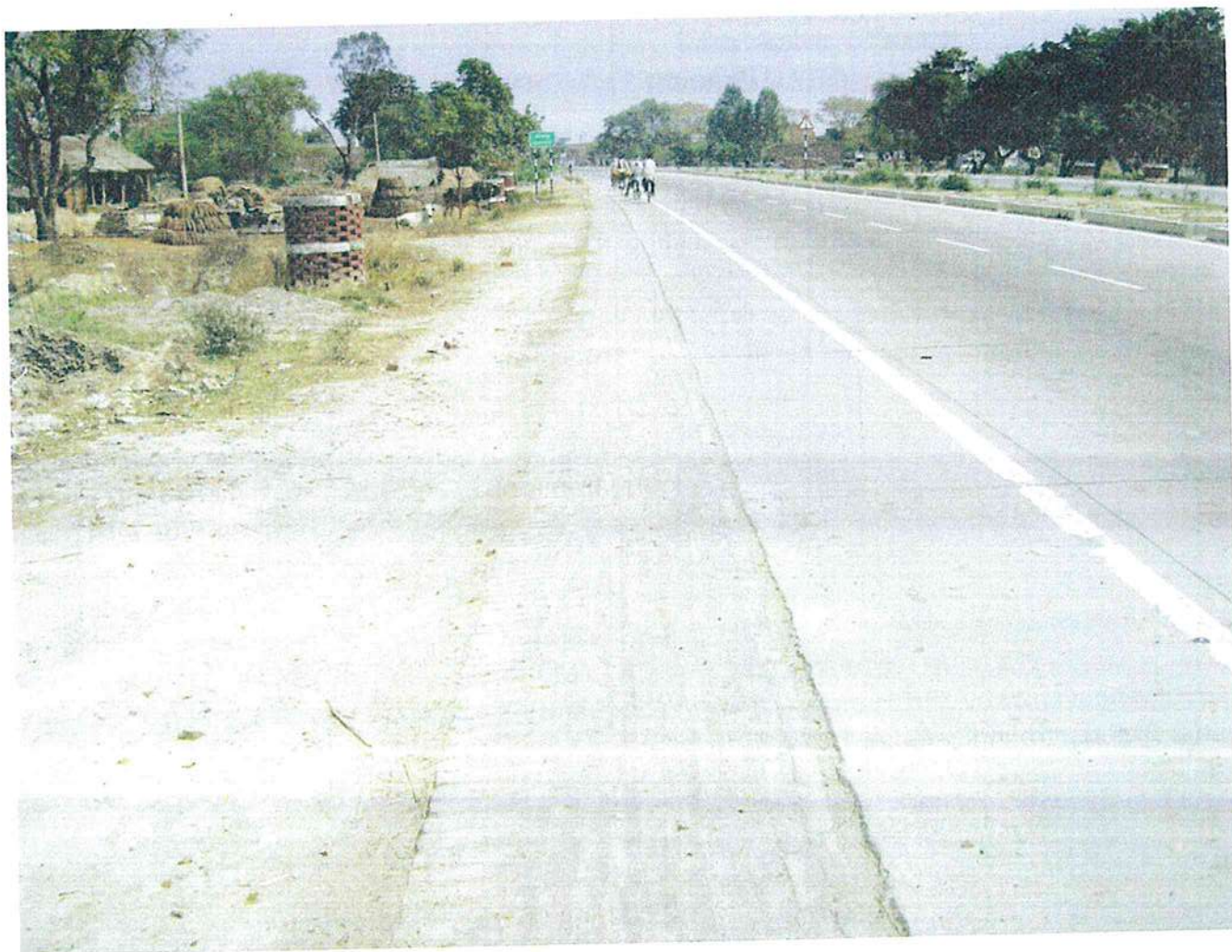


Photo 5 Construction of Brick on Edge (Paved Shoulder)

Reference:

- 1) Technical Paper by N.B. Lal and S.C.Sharma as published by Indian Roads Congress "International Seminar on Innovations in Construction and Maintenance of Flexible Pavements, Agra 2-4 September 2006", Pages 4-21 to 4-36.

DETAILS OF MU-METER AND BRITISH PENDULUM TEST

Mu-Meter: It is a battery-powered equipment used as a continuous friction measuring and reporting system, mainly designed for testing road surfaces, airport runways and taxiways. Features like fully shock absorbed suspension, aerodynamic fairings; and low centre of gravity ensure that the laterally loaded wheels remain in firm contact with the road surface at all times, even at high speeds.

This equipment consists of a small three-wheeled trailer (weight 254 kg) incorporating electronic measuring systems which operate in conjunction with a computer carried in the chosen towing vehicle. The trailer unit comprises of a triangular frame on which two friction measuring wheels are mounted as shown in **Fig. 1**. The built-in recorder of Mu-meter is shown in **Fig. 2**. The rear wheel which drives the recorder also measures the distance. It measures the sideways coefficient of friction generated between the test surface and the smooth tread tyres operating at 7.5 degrees angle to the directions of travel under the wet condition. The speed of measurement for normal recording is 64 km/hr. In Mu-meter, the force required to slide the tyre is divided by the wheel load and multiplied by 100 to calculate the skid number. The skid resistance numbers for various traffic speeds are indicated in **Table 1**.



Fig. 1 Mu-Meter Equipment



Fig. 2 Recorder of Mu-Meter Data

Table No. 1 Skid Resistance No. at different Speeds of Vehicles

Minimum SN	Traffic Speed (km/h)
36	50
33	65
32	80
31	95
31	110

Ref: ICPI (Inter-locking Concrete Pavement Institute) Spec. No. 13 1998 (Revised 2004), USA

British Pendulum Tester: The British pendulum test is a common procedure for laboratory as well as field measurement of the low-speed friction of a road surface material. It is widely suggested that the measured low-speed friction is largely governed by the surface microtexture of the road material, and many researchers and practitioners have considered the friction measurements made by the British pendulum test to be an indirect form of measurement of available microtexture of the road material. The test results demonstrated that the low-speed

friction measurements by the British pendulum tester (as shown in **Fig. 3**) were significantly affected by test surface macrotexture. British pendulum test may not produce a correct assessment of the skid resistance of the true road surface. The value measured by the tester is expressed in terms of British Pendulum Number (BPN). British Pendulum Tester gives higher skid resistance rating than dynamic tyre and trailer test. British Pendulum Number rating between 45 and 55 indicates a satisfactory surface in only favourable weather and vehicle conditions. Rating of 55 or greater indicates generally acceptable skid resistance (SN) in all conditions. A 65 and above rating indicates a good to excellent skid resistance in all conditions. The BPN measurements are taken on wet surface.

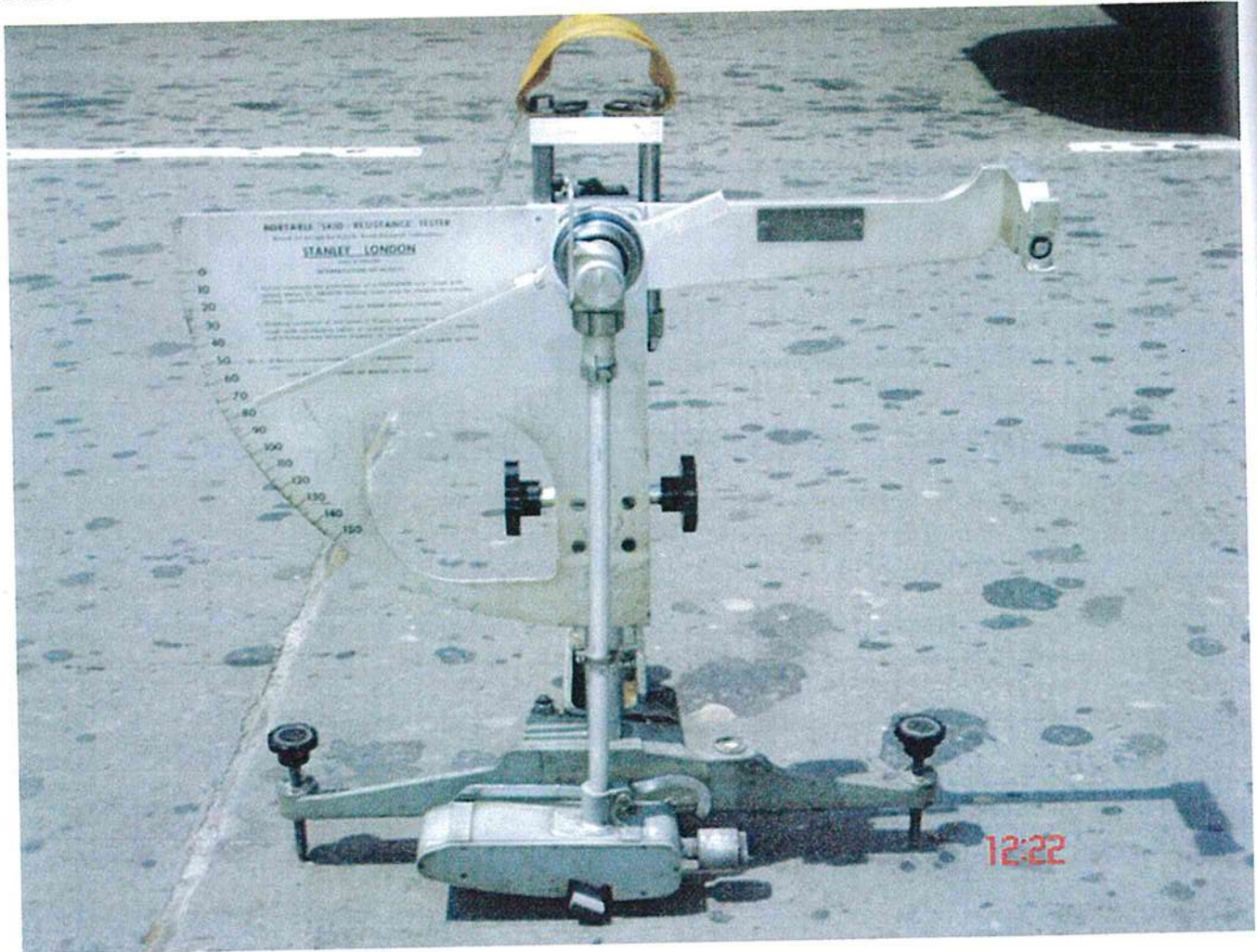


Fig. 3 British Pendulum Tester

